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RAPID HEATING AND LOADING OF 5052-H34 ALUMINUM ALLOY SHEET

by

John H. Honeycutt

March 1969

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U.S. ARMY MISSILE COMMAND

Redstone Arsenal, Alabama 35809

24 March 1969

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Materials Engineering and Development Branch
Structures and Mechanics Laboratory
Research and Engineering Directorate (Provisional)
U. S. Army Missile Command
Redstone Arsenal, Alabama 35809

ABSTRACT

The purpose of this report is to make available to the design engineer tensile property data on 5052-H34 aluminum under conditions of rapid heating and loading.

The tensile property data reported are: ultimate tensile stress; ultimate yield stress (at 0.2 percent offset); elastic modulus, percent total elongation, and percent uniform elongation. The uniform elongation was determined only at 0.0045 in./in./sec on the transverse specimens.

These tensile properties were determined at strain rates of 0.0045, 0.0262, and 0.0419 in./in./sec and at temperatures from room temperature (78°F) to 700°F at 100-degree intervals, excluding 100° and 200°F. The time required to reach the test temperature was, in most cases, less than 10 seconds.

In addition to the tensile property data, the angle of fracture of the material was also determined. These data are presented as byproducts of the tensile property data and only to investigate the possibility of establishing a trend for the angle of fracture at different strain rates and temperatures.

Primary consideration is given to ultimate tensile and yield properties. Other tensile property data reported are secondary and should be used for design criteria only after consideration has been given to the methods used for obtaining and reducing these data.

The strength properties of the test material increased with an increase in strain rate from 400° to 700°F. However, from room temperature to 400°F, the strength properties showed almost no change with respect to strain rate.

All tensile data indicated a decreasing trend with an increase in temperature except for total elongation, which established an increasing trend with an increase in temperature.

ACKNOWLEDGEMENT

The efforts of Malcolm Bumbalough in assembling the apparatus and modifying the electronics to provide accurate data and of Ronald Britton in aiding in the reduction of data are gratefully acknowledged.

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1. Introduction

Four aluminum alloys were selected fc tensile property evaluation at various strain rates and temperatures. These are: 2014-0, 2024-T3, 7075-T6, and 5052-H34. At this time, only the 5052-H34 alloy has been evaluated.

The controlling factor for the strain rates to be used is the test equipment now on hand. These strain rates are 0.0045, 0.0262, and 0.0419 in./in./sec. The strain rates are not constant and are an average of the strain rates for each test condition.

The temperature for this investigation ranged from room temperature (73°F) to 700°F at 100°F intervals, excluding 100° and 200°F. The test samples are resistance heated and the temperature manually controlled by visually monitoring a thermocouple output. The time required to reach test temperature was approximately 10 seconds for all specimens.

To record the test, an "X-Y" recorder was employed at the slower strain rate (0.0045 in./in./sec). At the other two strain rates (0.0262 and 0.0419 in./in./sec), an oscilloscope with a Polaroid camera was used to record the test data. The reason for the instrumentation change is that the X-Y recorder slew rate is 20 in./sec and the loading rate of the specimens at the two faster strain rates is greater than 20 in./sec, which is too fast for the recorder.

The number of specimens required to establish a data point was two — if the data agreed within 10 percent. If the data did not agree within 10 percent, a third specimen was tested.

The data used to plot the curves are averages of either the two or three data points recorded.

Testing of the three other alloys is being held in abeyance until new test equipment is installed. This new equipment will provide a controlled strain and an increase in the strain differential.

2. Test Material and Specimen

The 5052-H34 material used for this test was a sheet, 36 × 30 inches × 0.50 inch thick, furnished by the Reynolds Metals Company. No chemical composition was supplied. The test specimen configuration is shown in Figure 1.

3. Test Equipment

The test equipment used for tensile loading of the specimens was a Model TTD Instron universal testing machine with a full scale load capability of 20,000 pounds. Specimens were resistance-heated by use of a Marquardt TM9 power controller.

The recorder instrument used for the slower strain rate (0.0045 in./in./sec) was a model 2D Mosley X-Y recorder. A Tektronix Model 502A dual-beam oscilloscope with Polaroid camera attached was used to record data at the two faster strain rates (0.0262 and 0.0419 in./in./sec).

The temperature of the specimen was controlled manually during observation of the temperature recorder. The temperature recorder monitored a chromel-alumel thermocouple, which was attached to the center of the gage length of the specimen by percussive welding.

The specimen strain was measured by use of a clip-on type extensometer over the 2-inch gage length of the specimen (Figure 2).

A block diagram of the test setup and associated instrumentation is shown in Figure 3.

4. Data Measurement

The specimen load was measured with use of an Instron load cell. This is an electronically calibrated strain-gage type of load cell with load ranges of 500-, 1000-, 2000-, 5000-, 10,000-, and 20,000-pound ranges.

Strain measurements were made with use of the clip-on type extensometer. This extensometer consists of a 0.5-inch wide by 3-inch long piece of spring steel with appropriate clamps fastened to each end (Figure 2). There are two strain gages mounted on both the tension and compression side of the spring. The extensometer bridge network and physical arrangement of the gages are shown in Figure 4. This bridge arrangement is such that strain signals in R_1 and R_3 are additive in one direction and those of R_2 and R_4 are additive in the other direction, thus producing four times the electrical output of a single strain gage.

The strain rate for each test condition was measured by use of the second beam on the oscilloscope as an indication of strain only. A pulse generator caused the second beam to be displayed on the oscilloscope at a predetermined time interval of 15, 30, 60, or 100 milliseconds.

The strain rate beam sweep is shown in the upper part of Figure 5.

The strain rate reported for each condition was calculated from the load-strain curves at that condition. The strain rate was calculated over the portion of the curve from zero strain to the 0.2 percent offset yield point and is the average strain rate for each individual test sample (Figure 5).

In all cases the strain rate showed a definite increase after the specimen reached its proportional limit. This increase is a result of some of the cross-head movement being taken up by the elastic deformation of the test machine parts such as the load cell, pull rods, jaws, universal joints, and specimen shoulders.

Temperature measurements were read directly from a temperature meter, which is calibrated in degrees Fahrenheit. The meter was driven by a chromel-alumel thermocouple welded to the center of the gage length of the specimen. The temperature was manually controlled because of the slow response to temperature change of the automatic temperature controller.

The percent total elongation of each specimen was measured by use of a Riehle percent gage for a 2-inch gage length. In some instances, the specimens that were run at other than room temperature arced upon fracture and caused the ends of the fractured part of the specimen to melt (Figure 6). Because of the arcing and consequent melting of the material, it was not possible to measure the percent total elongation with a consistent degree of accuracy. In future tests of this type, elongation measurements will be taken from the load-strain curves.

The uniform elongation measurements were taken from the recorded data of the calibrated extensometer.

Uniform elongation was not included in the initial test plan. Therefore, the extensometer was calibrated only to cover the range of the specimens that would show the 0.2 percent offset yield. At a later time, a decision was made to report uniform elongation data. This required the installation of a new amplifier in the existing instrumentation to improve the linearity of the extensometer signal so that the entire elongation of the specimen could be recorded.

In previous tests, the linearity of the extensometer output was not considered important past the 0.2 percent offset yield. Figure 7 shows the two different curves with the improved linearity in the extensometer signal.

The angle of fracture of each specimen was measured with an adjustable protractor. A fracture perpendicular to the load axis was considered a fracture angle of zero degrees.

5. Test Procedure

Specimens oriented in both the longitudinal and transverse directions were evaluated. The longitudinal specimens were tested first. The test was started at the faster strain rate (0.0419 in./in./sec) and at each strain rate specimens were tested at 700°, 600°, 500°, 400°, and 300°F, and at room temperature. At each temperature, only two specimens were tested if the tensile data agreed within 10 percent. If the tensile data did not agree within 10 percent, a third specimen was tested. The average tensile data from the two or three specimens were then used as the data point to construct all curves.

At the beginning of each test, all specimens were marked and measured, and their areas calculated and recorded.

Before the beginning of each test period, a sample specimen was mounted in the test machine, and the temperature gradients were checked. When necessary, adjustments were made to keep the temperature gradients within 10°F or less over the gage length of the specimen. Periodic checks were made as required during the test period to maintain this minimum temperature gradient (Figure 8).

A specimen was clamped in the machine and a thermocouple percussively welded to the center of its gage length. The thermocouple was used to control and measure the temperature of the specimen. Next, the calibrated extensometer was clipped on the specimen and the specimen brought up to the desired temperature within 10 seconds or less. At this time, the load was applied to the specimen and the load-strain curve was recorded on the oscilloscope for the two faster strain rates (0.0419 and 0.0262 in./in./sec) and on the Moseley X-Y recorder at the slower strain rate (0.0045 in./in./sec).

During the test, the temperature was manually controlled by observation of the temperature meter. Manual control of the specimen temperature was held within ±10°F throughout the specimen test cycle.

The ultimate strength and 0.2 percent offset yield were determined from each calibrated load-strain curve. Modulus of elasticity was measured from the slope of the elastic portion of the load-strain curves (Figure 5). Total elongation was measured by use of a Riehle percent gage and the angle of fracture was measured with a protractor.

The strain rate for each test was calculated from the timing information on the oscilloscope trace as recorded on the load-strain curve (upper trace on the load-strain curve, Figure 5). As shown in this figure, the strain rate is 0.026 in./in./sec, from zero strain to the 0.2 percent offset yield load on the strain axis. From this point, 2 centimeters out on the strain axis, the strain rate increases to 0.046 in./in./sec. The reasons for the lower strain rate are that pull rods, universal joints, load cell, and specimen shoulders have some elastic deformation that takes up some of the movement of the crosshead, which travels at a constant rate. The strain rates reported here are average rates taken from the start of loading to the 0.2 percent offset yield strength.

Uniform elongation of the test samples was conducted only on the transverse samples at the slower strain rate of 0.0045 in./in./sec. In each test, the extensometer was left on the sample until failure. From the data plotted on the X-Y recorder, the uniform elongation was calculated by use of the recorded values of strain from the calibrated extensometer.

Figure 9 shows a typical load-strain curve from which the uniform elongation is calculated.

6. Test Results

The results of these tests are shown in tabular form in Tables I through VI. The curves representing the average tabulated values are shown in Figures 10 through 26. The data points of each curve are an average of either two or three specimens as shown in the tabulated data.

a. Tensile Properties

Ultimate tensile properties decreased moderately with an increase in temperature up to 400°F. However, past 400°F, the strength properties decrease sharply to 700°F. Conversion of data points at 700°F suggests that all strength characteristics are depleted at this temperature.

The strain rates appear to have almost no effect on stress values except above 400°F. In the temperature range from 400° to 700°F, the stress level increases with an increase in strain rate. Transverse and longitudinal curves show the same trends except for a point at room temperature and 0.0045 in./in./sec strain in transverse curves. Data for this point were taken from a different lot of 5052-H34, which had an increase in thickness of 0.013 inch. The reason for this particular point being lower than the other points at this same condition could possibly be attributed to "size effect."

TABLE I. TENSILE PROPERTIES OF 5052-H34 ALUMINUM AT DIFFERENT TEMPERATURES AND STRAIN RATES

Longitudinal Specimens

Spec. No.	Spec. Area	Temperature (°F)	Strain Rate (in./in./sec)	Ultimate Load (lb)	Ultimate Stress (psi)	Yield 0.2 Percent Offset (lb)	Yield Stress (psi)	Elastic Modulus × 10^6 (psi)	Elongation Total (%)	Elongation Uniform (%)	Angle of Fracture (deg)
	0.0253	700	0.0500	256	10,100	203	8004	8.2	31	--	3
	0.0252	700	0.0492	273	10,460	207	7931	7.1	30	--	2
	0.0264	700	0.0492	273	10,341	226	8570	7.3	30	--	2
av.			0.0495	267	10,300	212	8168	7.5	30	--	2.3
	0.0253	600	0.0508	438	17,312	388	15,360	6.2	15	--	2
	0.0251	600	0.0500	507	20,199	450	17,928	6.8	16	--	6
av.			0.0504	473	18,756	419	16,644	6.5	15.5	--	4
	0.0252	500	0.0450	650	25,794	527	23,611	9.0	9	--	8
	0.0255	500	0.0508	630	24,706	515	22,745	7.7	10	--	2
	0.0253	500	0.0517	640	25,296	510	21,937	9.2	9	--	4
av.			0.0458	640	25,265	517	22,764	8.6	9.3	--	5
	0.0263	400	0.0433	830	31,559	680	28,707	11.8	5	--	22
	0.0256	400	0.0425	815	31,836	680	27,734	12.2	5	--	20
av.			0.0429	823	31,698	680	28,220	12.0	5	--	21
	0.0259	300	0.0392	885	34,170	705	29,151	11.4	5	--	22
	0.0256	300	0.0442	850	33,203	665	27,539	13.0	5	--	22
	0.0264	300	0.0400	890	33,712	725	29,167	13.0	5	--	22
av.			0.0411	875	33,695	698	28,619	12.5	5	--	22
	0.0257	RT	0.0358	960	37,354	750	31,128	13.4	7	--	20
	0.0264	RT	0.0375	985	37,311	750	30,492	14.0	7	--	20
	0.0263	RT	0.0375	975	37,072	750	30,418	14.6	7	--	20
av.			0.0369	973	37,246	750	30,679	14.0	7	--	20
		Avg	0.0444								

TABLE II. TENSILE PROPERTIES OF 5052-H34 ALUMINUM AT DIFFERENT TEMPERATURES AND STRAIN RATES

Transverse Specimens

Spec. No.	Spec. Area	Temperature (°F)	Strain Rate (in./in./sec)	Ultimate Load (lb)	Ultimate Stress (psi)	Yield 0.2 Percent Offset (lb)	Yield Stress (psi)	Elastic Modulus × 10^6 (psi)	Elongation Total (%)	Elongation Uniform (%)	Angle of Fracture (deg)
	0.0251	700		241	9612	182	7271	11.1	[illegible]	--	1
	0.0251	700	0.0400	242	9661	211	8406	10.0	34	--	1
av.			0.0400	242	9637	197	7839	10.6	34	--	1
	0.0251	600	0.0433			423	16,853	10.0	10	--	3
	0.0259	600	0.0425	530	20,463	470	15,147	10.7	11	--	4
av.			0.0429	530	20,463	447	17,500	10.4	10.5	--	3.5
	0.0254	500	0.0400	682	26,850	605	23,819	14.0	10	--	4
	0.0258	500	0.0433	682	26,453	628	24,322	10.8	10	--	7
	0.0256	500	0.0350	670	26,171	603	23,535	13.0	8	--	10
av.			0.0394	678	26,491	612	23,892	12.6	9.3	--	7
	0.0251	400	0.0450	800	31,872	700	27,8[illegible]8	15.9	6	--	26
	0.0251	400	0.0367	810	32,270	690	27,490	19.0	6	--	25
	0.0251	400	0.0383	810	32,270	695	27,689	15.9	6	--	27
av.			0.0400	807	32,137	695	27,689	16.9	6	--	25
	0.0252	300	0.0416	915	36,390	760	30,159	15.3	6	--	31
	0.0252	300	0.0342	905	35,910	755	29,960	17.3	6	--	31
	0.0251	300	0.0408	915	36,454	745	29,681	15.9	6	--	31
av.			0.0389	912	36,251	753	29,945	16.2	6	--	31
	0.0257	RT	0.0342	1010	39,299	795	30,934	20.5	8	--	32
	0.0251	RT	0.0350	990	39,442	780	31,076	20.9	8	--	30
av.			0.0346	1000	39,371	788	31,005	20.7	8	--	31
			0.0393								

TABLE III. TENSILE PROPERTIES OF 5052-H34 ALUMINUM AT DIFFERENT TEMPERATURES AND STRAIN RATES

Longitudinal Specimens

Spec. No.	Spec. Area	Temperature (°F)	Strain Rate (in./in./sec)	Ultimate Load (lb)	Ultimate Stress (psi)	Yield 0.2 Percent Offset (lb)	Yield Stress (psi)	Elastic Modulus × 10^6 (psi)	Elongation Total (%)	Elongation Uniform (%)	Angle of Fracture (deg)
	0.0252	700	0.0275	225	8928	213	8432	6.6	31	--	0
	0.0261	700	0.0267	208	7969	198	7567	6.8	30	--	0
	0.0252	700	0.0242	206	8175	199	7887	6.4	33	--	0
av.			0.0261	213	8357	203	7962	6.6	31.3	--	0
	0.0253	600	0.0267	325	12,346	289	11,413	7.6	19.0	--	5
	0.0267	600	0.0250	369	13,811	326	12,219	5.2	25.0	--	0
	0.0266	600	0.0267	366	13,759	313	11,748	7.2	21.0	--	4
av.			0.0261	353	13,472	309	11,793	6.7	21.7	--	3
	0.0257	500	0.0225	598	23,249	550	21,401	8.1	11.0	--	2.5
	0.0265	500	0.0167	577	21,773	525	19,811	8.2	14.5	--	3.5
av.			0.0196	588	22,511	538	20,606	8.2	12.3	--	3.0
	0.0254	400	0.0150	800	31,496	770	30,315	9.8	7.5	--	13.5
	0.0253	400	0.0367	800	31,496	725	28,656	10.4	7.0	--	15.0
	0.0265	400	0.0258	812	30,660	755	28,491	10.4	6.5	--	21.0
av.			0.0258	804	31,217	740	29,154	10.2	7.0	--	16.5
	0.0267	300	0.0275	900	33,707	845	31,647	10.7	5.5	--	21
	0.0255	300	0.0258	845	33,137	790	30,980	10.9	5.5	--	19
av.			0.0267	873	33,422	818	31,327	10.8	5.5	--	20
	0.0254	RT	0.0317	925	36,417	795	31,299	11.6	7.0	--	21
	0.0253	RT	0.0275	910	35,968	795	31,299	11.9	7.0	--	22.5
av.			0.0296	918	36,193	795	31,299	11.8	7.0	--	21.8
		Avg	0.0257								

TABLE IV. TENSILE PROPERTIES OF 5052-H34 ALUMINUM AT DIFFERENT TEMPERATURES AND STRAIN RATES

Transverse Specimens

Spec. No.	Spec. Area	Temperature (°F)	Strain Rate (in./in./sec)	Ultimate Load (lb)	Ultimate Stress (psi)	Yield 0.2 Percent Offset (lb)	Yield Stress (psi)	Elastic Modulus $\times 10^6$ (psi)	Elongation Total (%)	Elongation Uniform (%)	Angle of Fracture (deg)
	0.0249	700	0.0275	199	7991	194	7781	5.9	31	--	0
	0.0252	700	0.0283	200	7936	192	7640	6.2	39	--	0
av.			0.0279	200	7964	193	7711	6.1	30	--	0
	0.0252	600	0.0258	385	15,277	363	14,384	6.2	15	--	3
	0.0249	600	0.0200	416	16,716	378	15,160	5.9	18	--	2
	0.0249	600	0.0225	390	15,662	358	14,357	5.0	18	--	2
av.			0.0228	397	15,885	366	14,634	5.7	17	--	2.3
	0.0251	500	0.0208	612	24,402	575	22,908	7.4	13.5	--	0
	0.0250	500	0.0217	600	24,000	575	22,908	8.0	13.0	--	0
av.			0.0213	606	24,201	575	22,908	7.7	13.3	--	0
	0.0251	400	0.0325	770	30,677	695	27,689	10.2	7	--	22
	0.0249	400	0.0275	790	31,726	705	28,313	10.3	9	--	14
av.			0.0300	780	31,202	700	28,000	10.3	8	--	18
	0.0249	300	0.0258	895	35,940	775	31,124	10.5	6	--	31
	0.0260	300	0.0242	975	37,500	850	32,692	10.7	6	--	31
av.			0.0250	935	36,720	813	31,908	10.6	6	--	31
	0.0251	RT	0.0325	1000	39,840	805	32,071	12.8	9.0	--	30
	0.0250	RT	0.0317	995	39,800	800	32,000	13.1	8.0	--	30
	0.0250	RT	0.0350	950	38,000	795	31,800	13.8	7.5	--	30
av.			0.0331	982	39,213	800	31,957	13.2	8.2	--	30
		Avg	0.0267								

TABLE V. TENSILE PROPERTIES OF 5052-H34 ALUMINUM AT DIFFERENT TEMPERATURES AND STRAIN RATES

Longitudinal Specimens

Spec. No.	Spec. Area	Temperature (°F)	Strain Rate (in./in./sec)	Ultimate Load (lb)	Ultimate Stress (psi)	Yield 0.2 Percent Offset (lb)	Yield Stress (psi)	Elastic Modulus × 10^6 (psi)	Elongation Total (%)	Elongation Uniform (%)	Angle of Fracture (deg)
	0.0245	700	0.0062	165	6735	158	6449	7.6	27	--	0
	0.0254	700	0.0063	175	6890	156	6535	6.2	28	--	2
	0.0250	700	0.0053	179	7160	173	6920	6.2	35	--	0
av.			0.0059	173	6928	166	6635	6.7	30	--	0.7
	0.0259	600	0.0056	250	9653	210	8108	6.2	31	--	2
	0.0252	600	0.0057	250	9921	175	6944	6.4	28	--	2
	0.0252	600	0.0055	238	9444	188	7460	6.8	32	--	2
av.			0.0056	246	6973	191	7504	6.5	30	--	2
	0.0266	500	0.0053	438	16,466	350	13,158	8.5	25	--	1
	0.0255	500	0.0047	445	17,451	365	14,314	8.3	26	--	2
av.			0.0050	442	16,959	358	13,736	8.4	25.5	--	1.5
	0.0265	400	0.0045	730	29,169	698	27,870	8.0	11	--	9
	0.0259	400	0.0045	728	29,070	708	25,271	7.9	12	--	0
av.			0.0045	729	29,120	703	28,071	8.0	11.5	--	4.5
	0.0262	300	0.0038	890	33,969	835	31,870	8.9	6	--	20
	0.0255	300	0.0041	870	34,118	800	31,373	9.9	7	--	10
av.			0.0040	880	34,044	818	31,622	9.4	6.5	--	15
	0.0252	RT	0.0046	950	37,698	840	33,233	10.8	7	--	22
	0.0268	RT	0.0037	968	36,119	850	31,716	11.4	7	--	24
av.			0.0042	959	36,909	845	32,525	11.1	7	--	23
		Avg	0.0049								

TABLE VI. TENSILE PROPERTIES OF 5052-H34 ALUMINUM AT DIFFERENT TEMPERATURES AND STRAIN RATES

Transverse Specimens

Spec. No.	Spec. Area	Temperature (°F)	Strain Rate (in./in./sec)	Ultimate Load (lb)	Ultimate Stress (psi)	Yield 0.2 Percent Offset (lb)	Yield Stress (psi)	Elastic Modulus × 10⁶ (psi)	Elongation Total (%)	Elongation Uniform (%)	Angle of Fracture (deg)
	0.0250	700	0.0062	175	7000	165	6600	3.7	38	0.24	0
	0.0251	700	0.0050	187	7420	185	7370	5.4	37	0.24	0
	0.0248	700	0.0042	188	7560	184	7409	4.5	35	0.29	0
av.			0.0051	183	7327	178	7126	4.5	36.7	0.26	0
	0.0248	600	--*	301	12,137	283	11,411	3.65	22	1.58	0
	0.0247	600	--	297	12,027	275	11,134	4.22	23	1.83	0
	0.0246	600	--	295	11,991	274	11,138	4.38	21	1.40	0
av.				298	12,052	277	11,228	4.08	22	1.60	0
	0.0249	500	0.0040	538	21,607	502	20,160	5.2	16	1.5	1
	0.0239	500	0.0040	525	21,968	490	20,502	6.1	16	1.4	1
av			0.0040	532	21,788	496	20,331	5.7	16	1.45	1
	0.0249	400	0.0035	773	31,004	730	29,317	7.24	11	1.8	3
	0.0245	400	0.0035	728	29,714	698	28,469	7.01	10	1.8	6
av.			0.0035	751	30,359	710	28,893	7.43	10.5	1.8	4.5
	0.0244	300	0.0030	878	35,963	775	31,762	8.4	12.0	4.4	30
	0.0244	300	0.0030	870	35,655	775	31,762	8.3	12.0	4.0	30
av.			0.0030	874	35,809	775	31,762	8.35	12.0	4.2	30
	0.0312	RT	--*	1100	35,255	893	28,620	8.9	10	7.2	25
	0.0312	RT	--	1095	35,095	850	27,243	9.1	10	8.1	25
	0.0312	RT	--	1095	35,095	865	27,243	9.1	11	7.7	25
av.				1097	35,148	869	27,862	9.0	10	7.7	25
		Avg	0.0039								

*No strain data are available at this temperature.

b. Yield Properties of 0.2 Percent Offset

The 0.02 percent offset yield curves for both longitudinal and transverse data show approximately the same trends as the ultimate tensile curves. The transverse curve also shows the low data point at room temperature and 0.0045 in./in./sec strain rate.

c. Elastic Modulus

The elastic modulus curves show a decrease in modulus with an increase in temperature. The change in modulus value with respect to strain rate is more pronounced for the transverse specimens than for the longitudinal specimens. At the faster strain rate the transverse specimens exhibit higher modulus values at corresponding temperatures than the longitudinal specimens. At the slowest strain rate just the opposite is true. That is, the modulus values at corresponding temperatures are higher for the longitudinal specimens than for the transverse specimens.

At the intermediate strain rate, both the longitudinal and transverse specimens have approximately the same modulus value at corresponding temperatures, the greatest deviation in the two curves being 19 percent at 600°F.

The longitudinal specimens are observed to converge at 500°F and remain at approximately the same modulus values at corresponding temperatures throughout the remainder of this test.

d. Total Elongation

The total elongation of the longitudinal specimens showed little change from room temperature to 300°F. However, from 300° to 700°F the total elongation increased sharply for each strain rate. The slow, intermediate, and fast strain rates, at corresponding temperatures, exhibit greater total elongation respectively.

The trend for total elongation of the transverse specimens shows an increase in elongation with an increase in temperature. The transverse test also exhibits an increase in total elongation with decreasing strain rate except for values at 700°F. At this temperature, the total elongation for the faster strain rate is greater than that for the intermediate strain rate. This is probably caused by the arcing and melting of the specimen immediately after fracture. Figures 27 and 28 show the specimens used to construct this data point.

Specimens A represent the intermediate strain rate at 700°F and specimens B represent the fast strain rate at 700°F. It is noteworthy that specimens B show no arcing. These specimens were prevented from arcing by cutting the power input immediately before fracture. However, specimens A were run with full power until after fracture causing arcing and melting of the specimens.

As previously stated, all future measurements of this type will be taken from the recorded data rather than from measurements by use of the Riehle percent gage.

e. Uniform Elongation

Uniform elongation was recorded only for the slower strain rate (0.0045 in./in./sec) on the transverse specimens.

Uniform elongation is considered to be the elongation of the specimen that occurs before any decrease in load is observed on the recorded data. It is therefore the useable elongation in design. All the uniform elongation data were taken from the X-Y recorder. The trend of uniform elongation in relation to temperature is just the reverse of that exhibited by total elongation, decreasing with increasing temperature. On the missile design, this type of data can be extremely important where low factors of safety inherent in "one-shot" hardware are used.

f. Angle of Fracture

The angle of fracture for both longitudinal and transverse specimens varied erractically with temperature. There is a maximum change of only 2 degrees from room temperature to 300°F for the transverse specimens. From 300° to 500°F, the maximum differential occurs for all strain rates. From 500° to 700°F, only a slight change of 3 degrees is noted for any of the strain rates. At all strain rates and corresponding temperatures, the angle of fracture of the transverse specimens is greater than the angle of fracture of the longitudinal specimens.

No effort has been made to analyze the angle of fracture data by crystallographic or other means and they are reported simply as a matter of interest.

g. Stress-Strain

The stress-strain curves for all strain rates show an increase in stress with decreasing temperature, with two exceptions. These exceptions are the room temperature transverse curves at 0.0262 in./in./sec strain and at 0.0045 in./in./sec strain. The room temperature curve for the 0.0262 in./in./sec strain rate has a stress level between the 300° and 400°F curves. The room temperature curve for the 0.0045 in./in./sec strain rate has a stress level above all other curves up to a value corresponding to 0.0034 in./in. strain. Past this value, the curve drops off and its end point is between the 400° and 500°F curves.

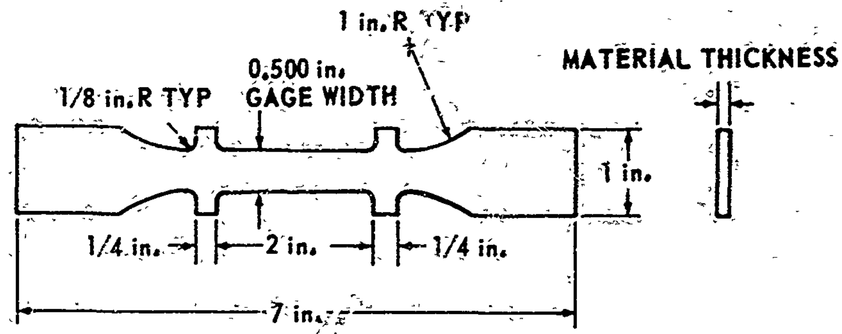
The effect of increased strain rate shows an increase in stress level at corresponding temperatures for both the longitudinal and transverse specimens.

7. Conclusions

All properties evaluated in this test followed previously established trends with respect to temperature and strain rate. However, an established trend reported for uniform elongation had not been found at the time of this writing.

Strain rates used for test conditions were not differentiated sufficiently to establish unquestionable trends with respect to strain rates in most cases. The ultimate, yield, and total elongation curves from room temperature to 300°F of the longitudinal curves are examples of this condition.

For design of missiles, the uniform elongation is considered to be of significant importance and considerably more quantitative data concerning this parameter should be generated.



The thickness of machined specimens within the reduced section shall be uniform within 0.010 inch.

The ends of reduced section shall not differ in width by more than 0.002 inch. There may be a gradual taper in width from the ends to the center, but the width at either end shall not be more than 0.005 inch greater than the width at the center.

FIGURE 1. DIAGRAM OF TENSILE SPECIMEN

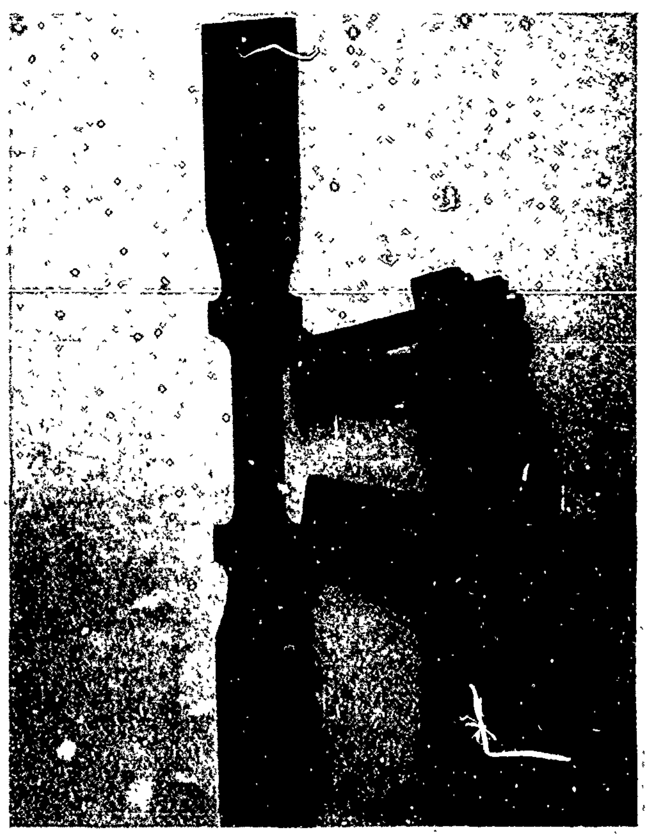


FIGURE 2. CLIP-ON EXTENSOMETER AND TEST SPECIMEN

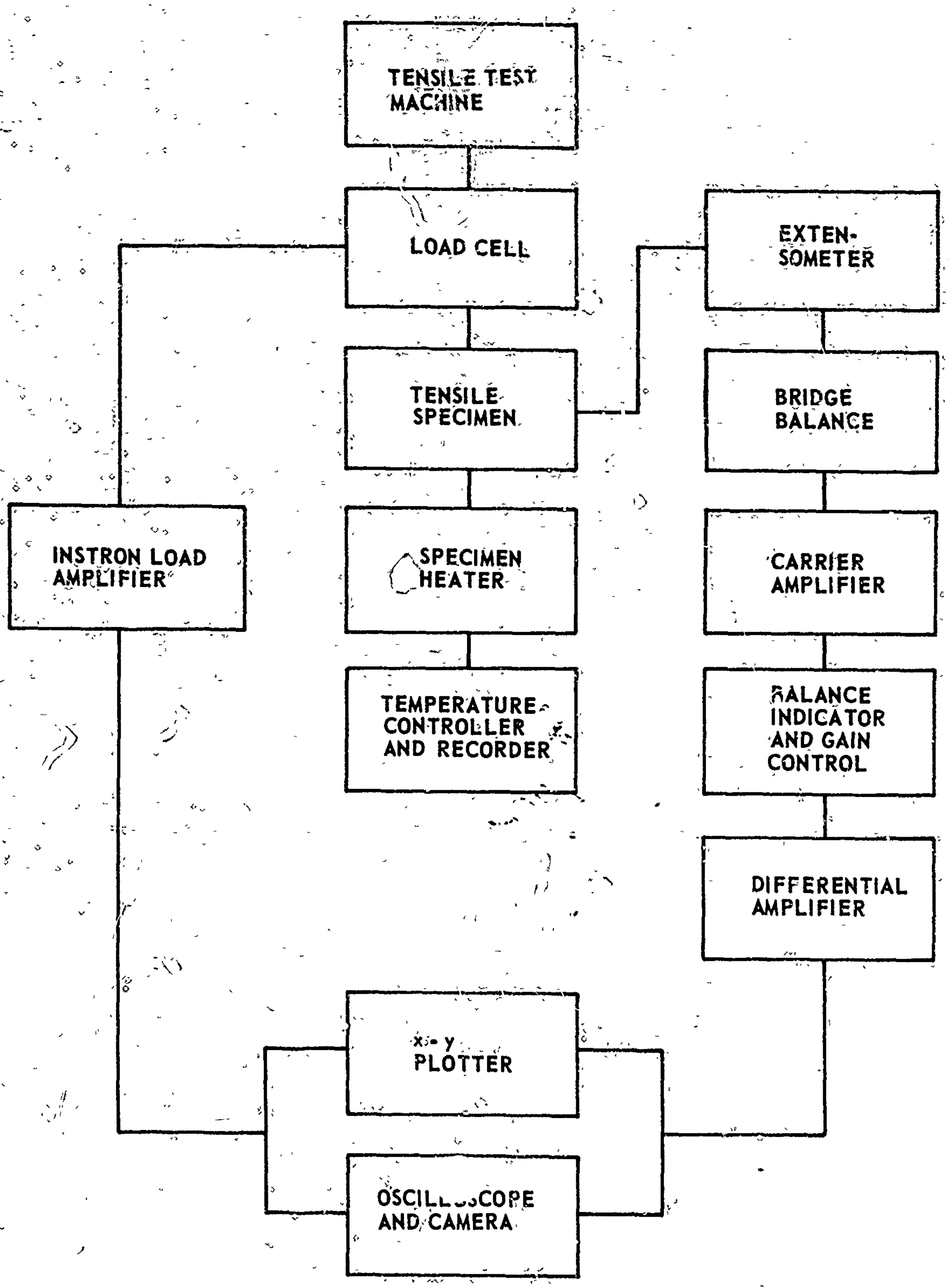


FIGURE 3. FUNCTIONAL DIAGRAM OF TEST SETUP

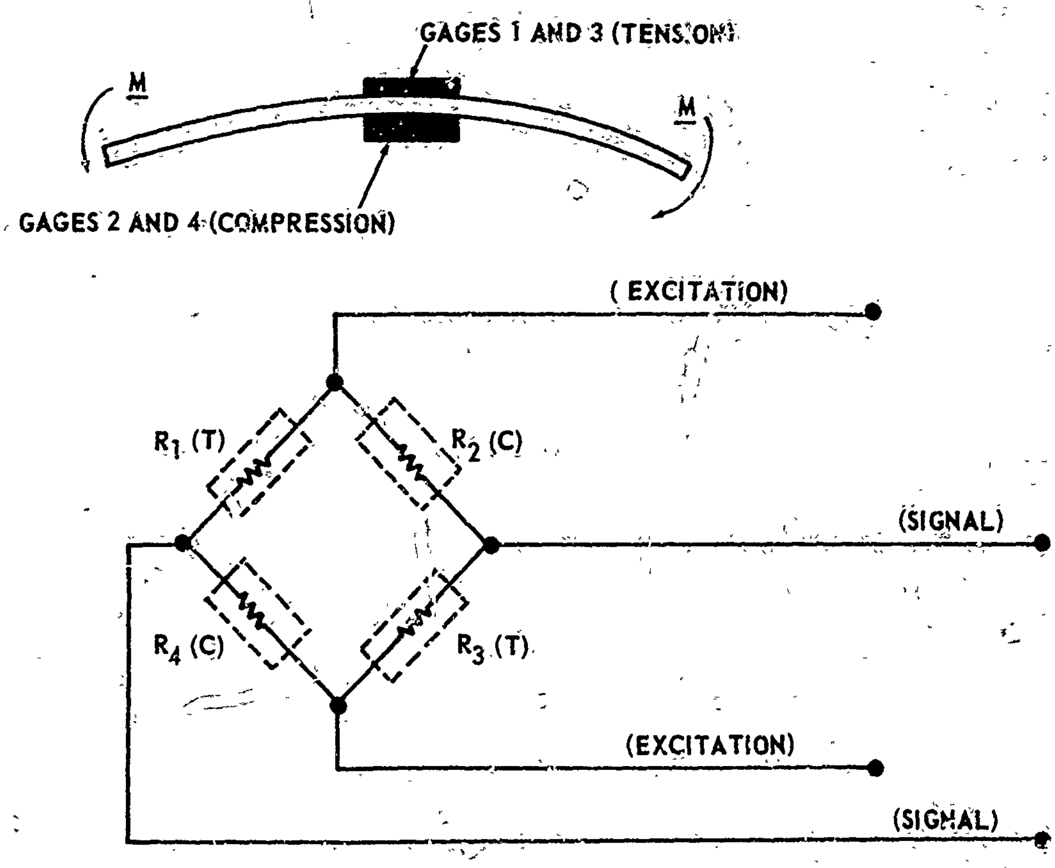


FIGURE 4. EXTENSOMETER PHYSICAL ARRANGEMENT AND BRIDGE NETWORK

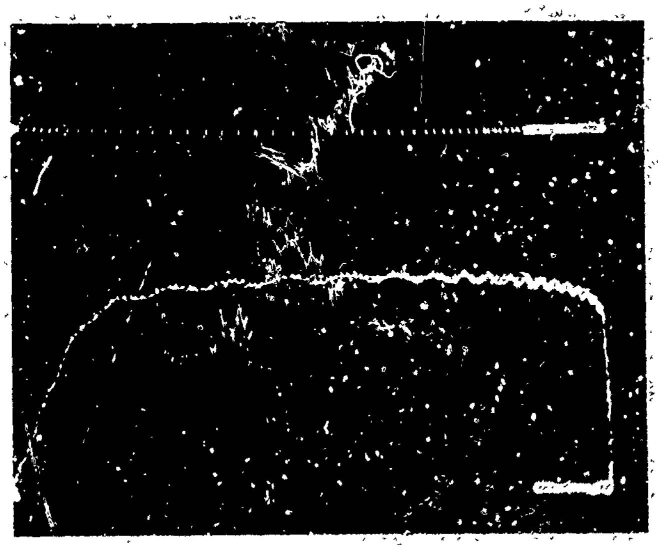


FIGURE 5. TYPICAL LOAD — STRAIN CURVE

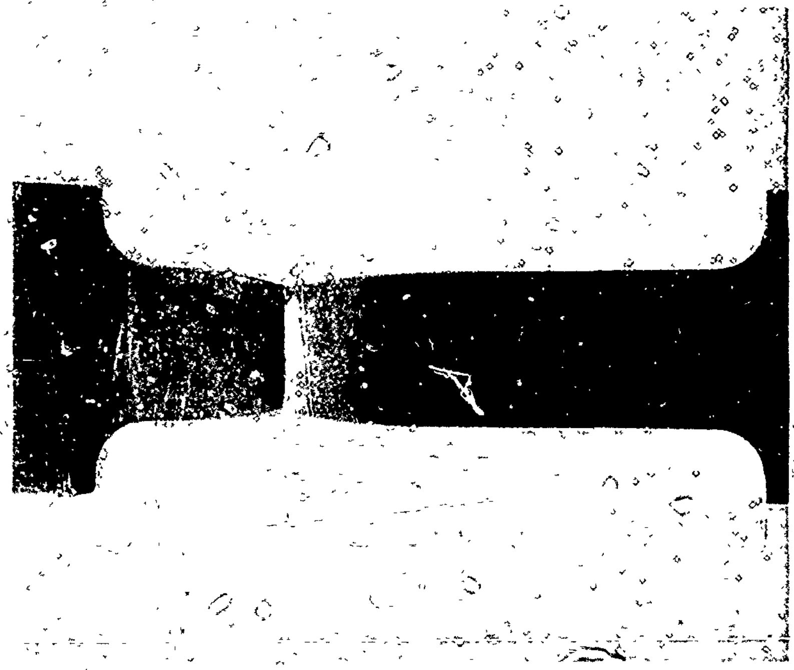
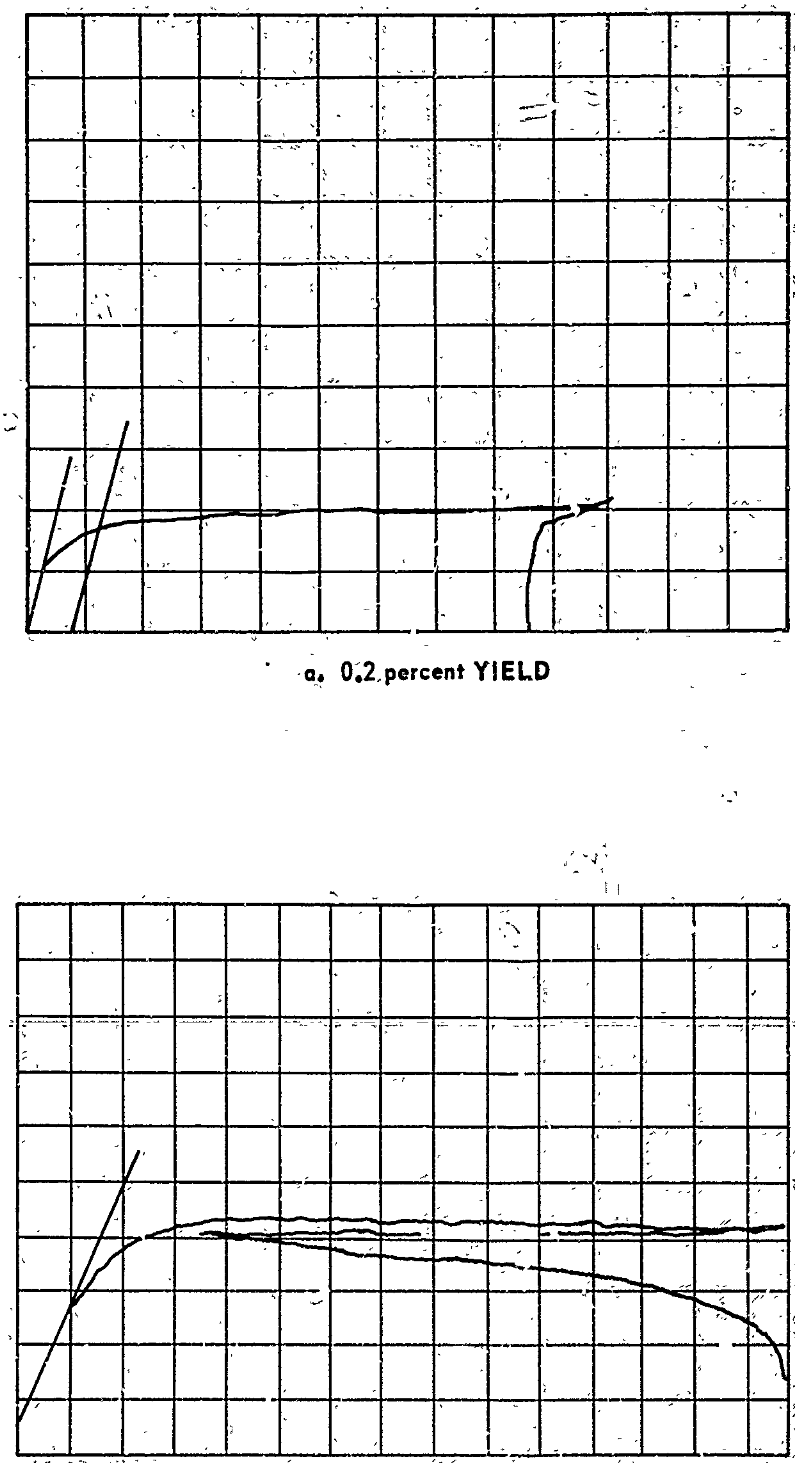


FIGURE 6. ARCING CONDITION SHOWN BY 500°F TEST SPECIMEN



a. 0.2 percent YIELD

b. UNIFORM ELONGATION

FIGURE 7. EXTENSOMETER LINEARITY TO INCLUDE 0.2 PERCENT EFFECT YIELD AND UNIFORM ELONGATION

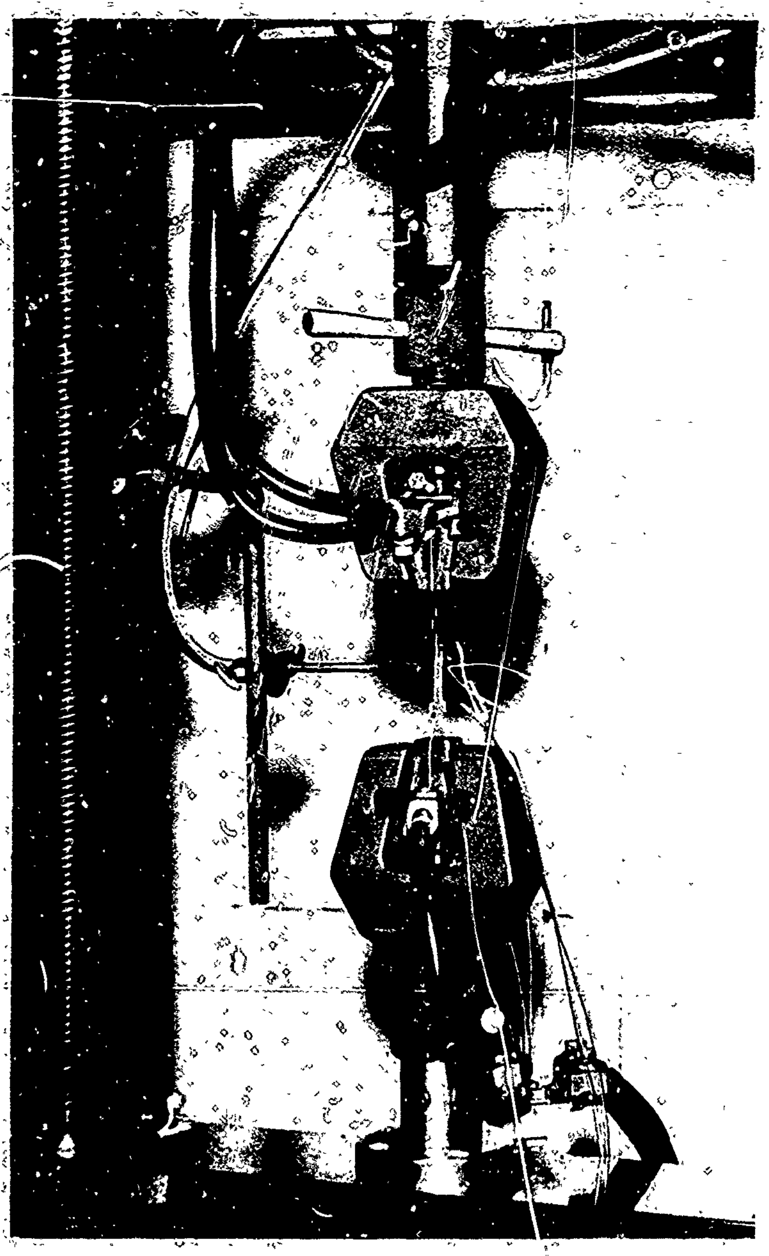


FIGURE 8. TEMPERATURE GRADIENT CHECKOUT

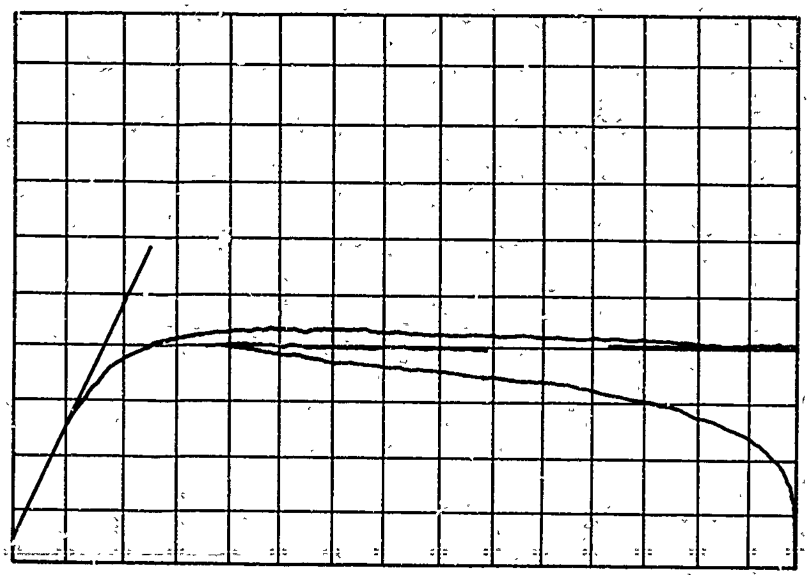


FIGURE 9. TYPICAL LOAD — STRAIN CURVE SHOWING UNIFORM ELONGATION DATA

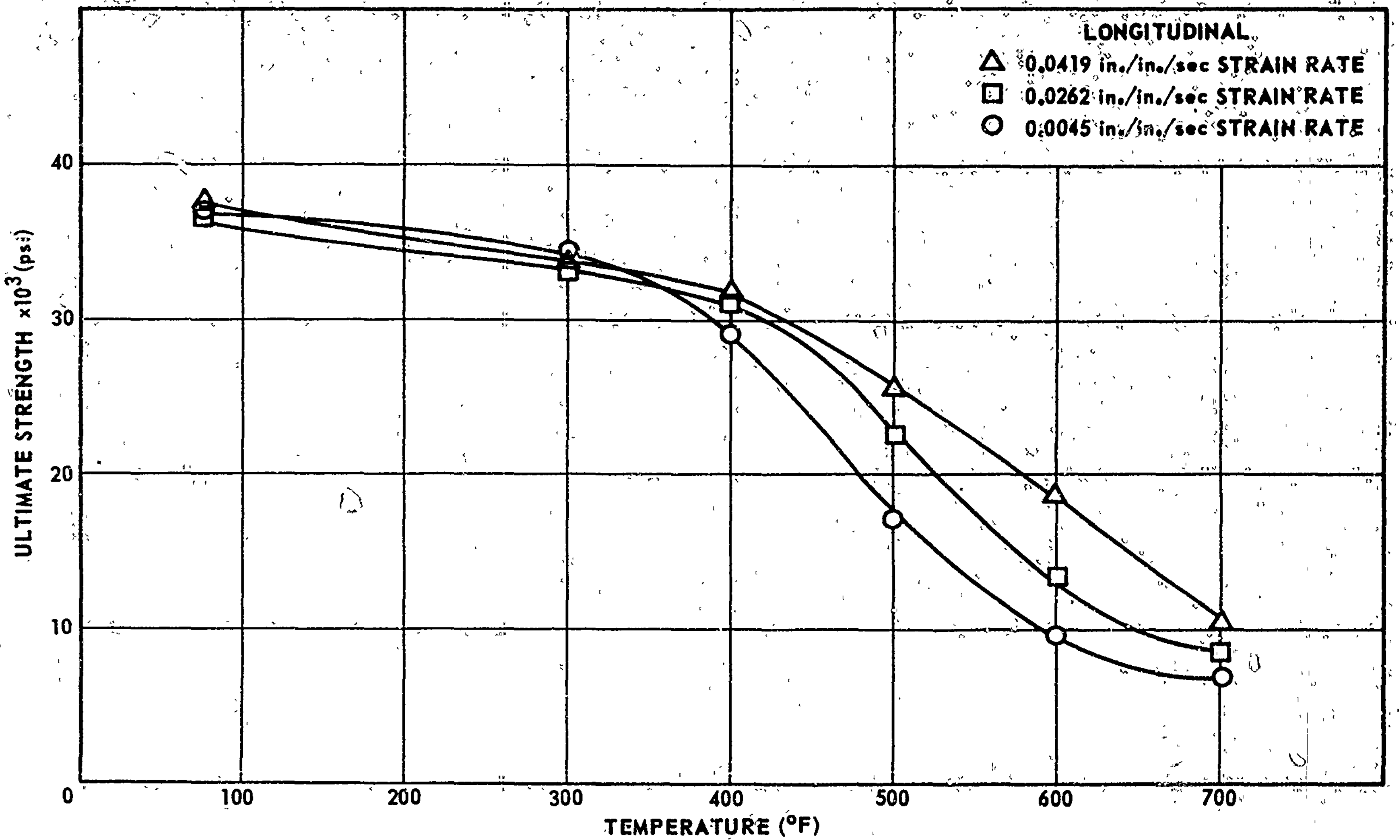


FIGURE 10. EFFECTS OF TEMPERATURE ON ULTIMATE TENSILE STRESS OF LONGITUDINAL SPECIMENS AT DIFFERENT STRAIN RATES

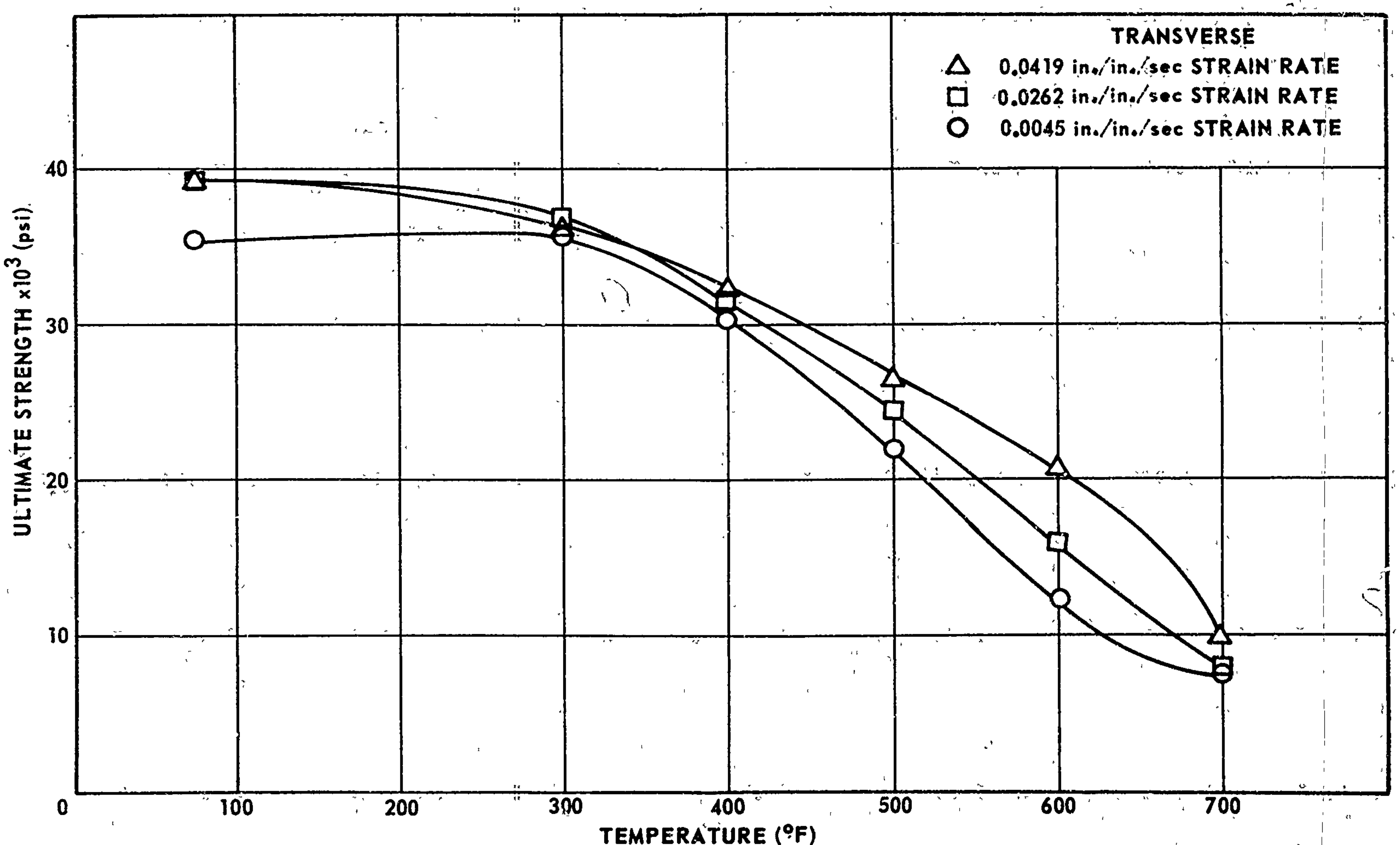


FIGURE 11. EFFECTS OF TEMPERATURE ON ULTIMATE TENSILE STRESS OF TRANSVERSE SPECIMENS AT DIFFERENT STRAIN RATES

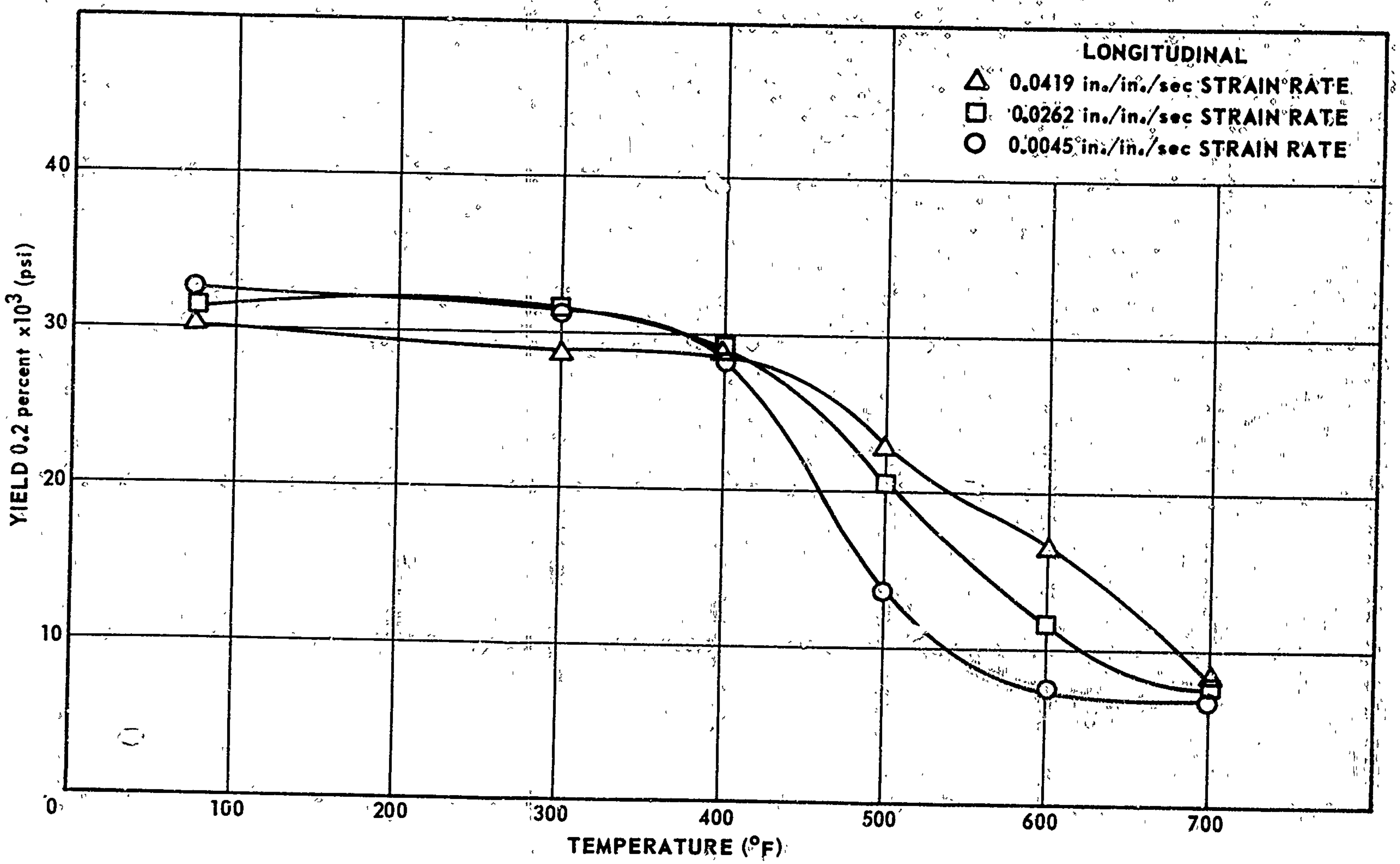


FIGURE 12. EFFECTS OF TEMPERATURE ON 0.2 PERCENT OFFSET YIELD STRESS OF LONGITUDINAL SPECIMENS AT DIFFERENT STRAIN RATES

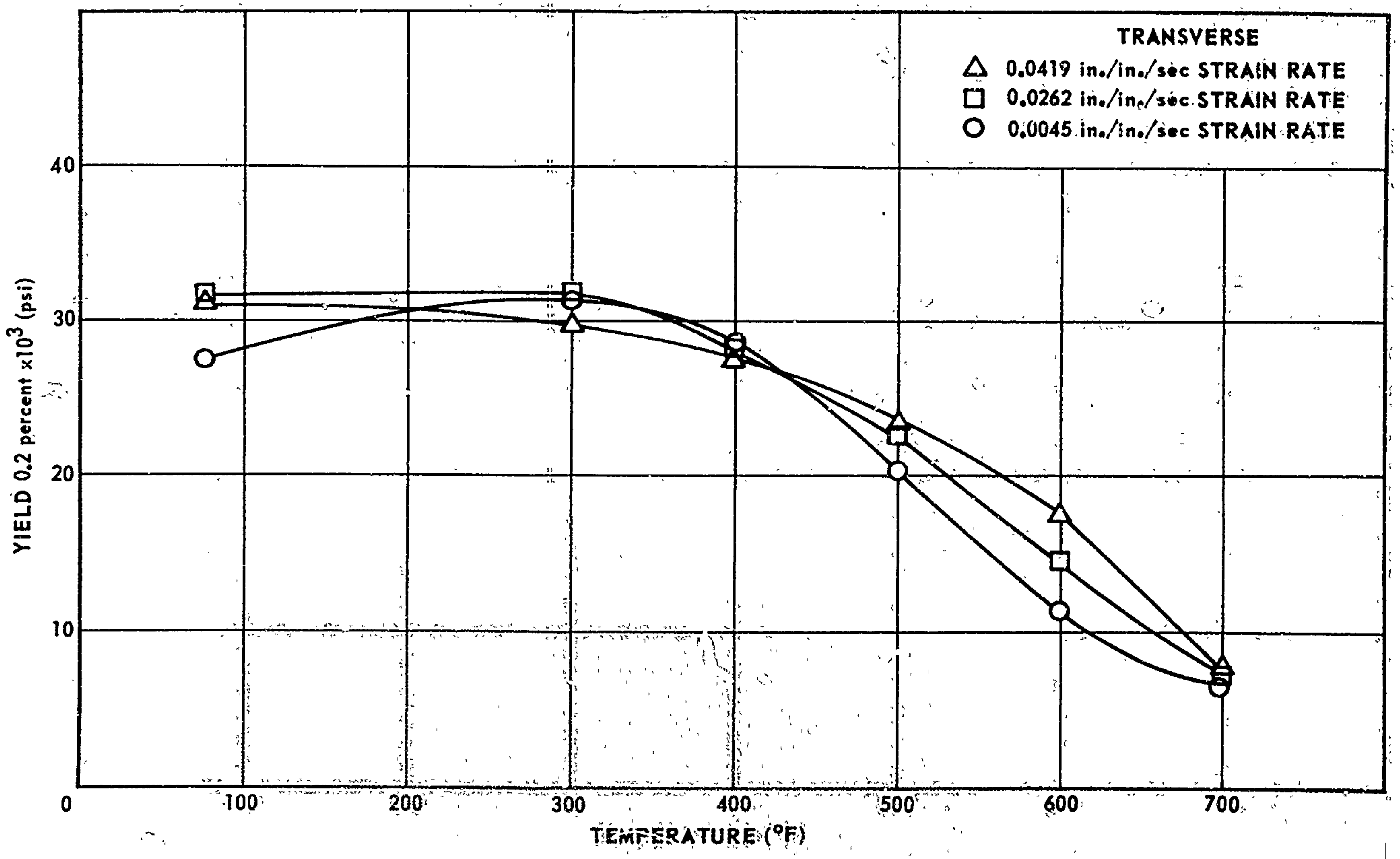


FIGURE 13. EFFECTS OF TEMPERATURE ON 0.2 PERCENT OFFSET YIELD STRESS OF TRANSVERSE SPECIMENS AT DIFFERENT STRAIN RATES

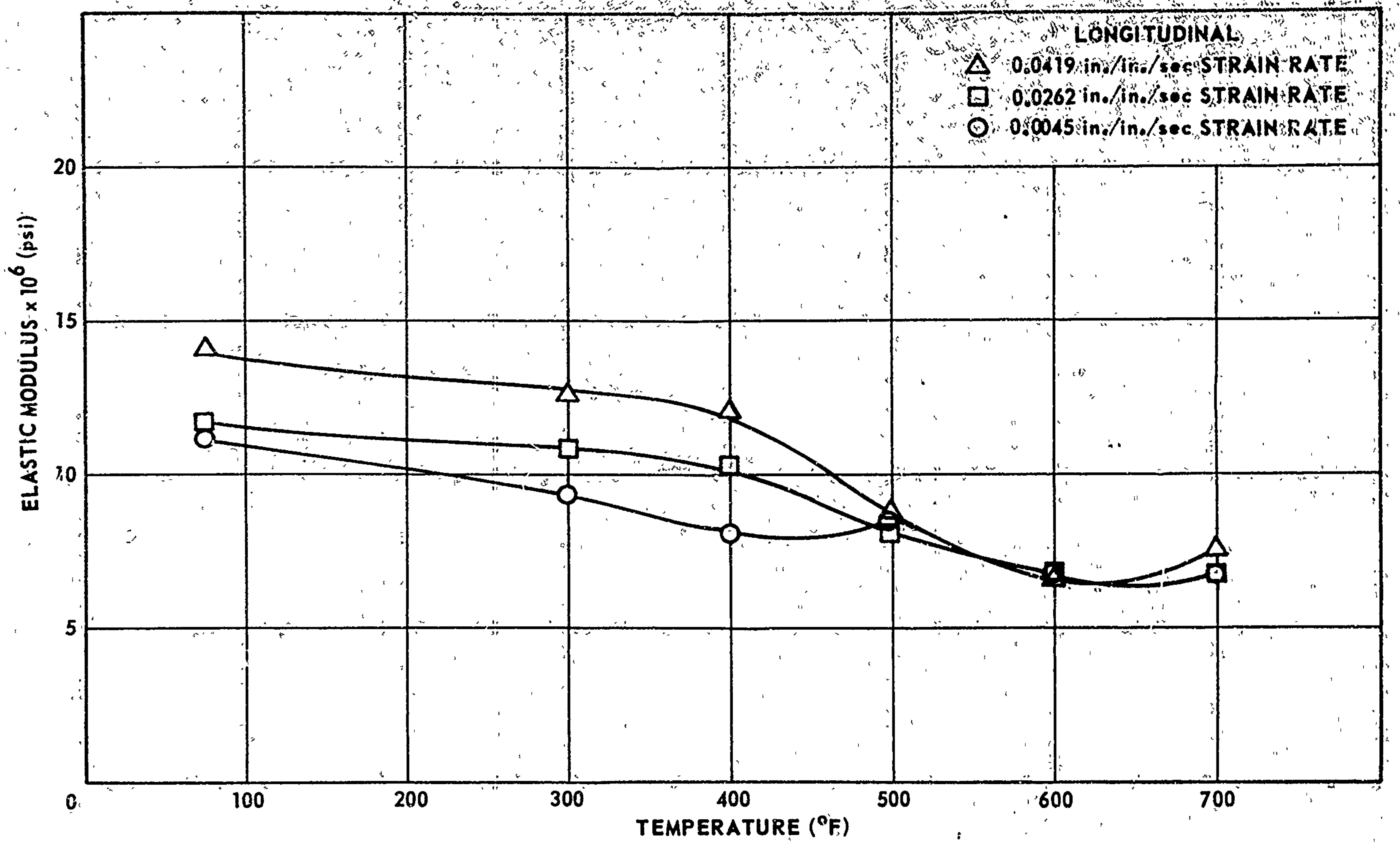


FIGURE 14. EFFECT OF TEMPERATURE ON ELASTIC MODULUS OF LONGITUDINAL SPECIMENS AT DIFFERENT STRAIN RATES

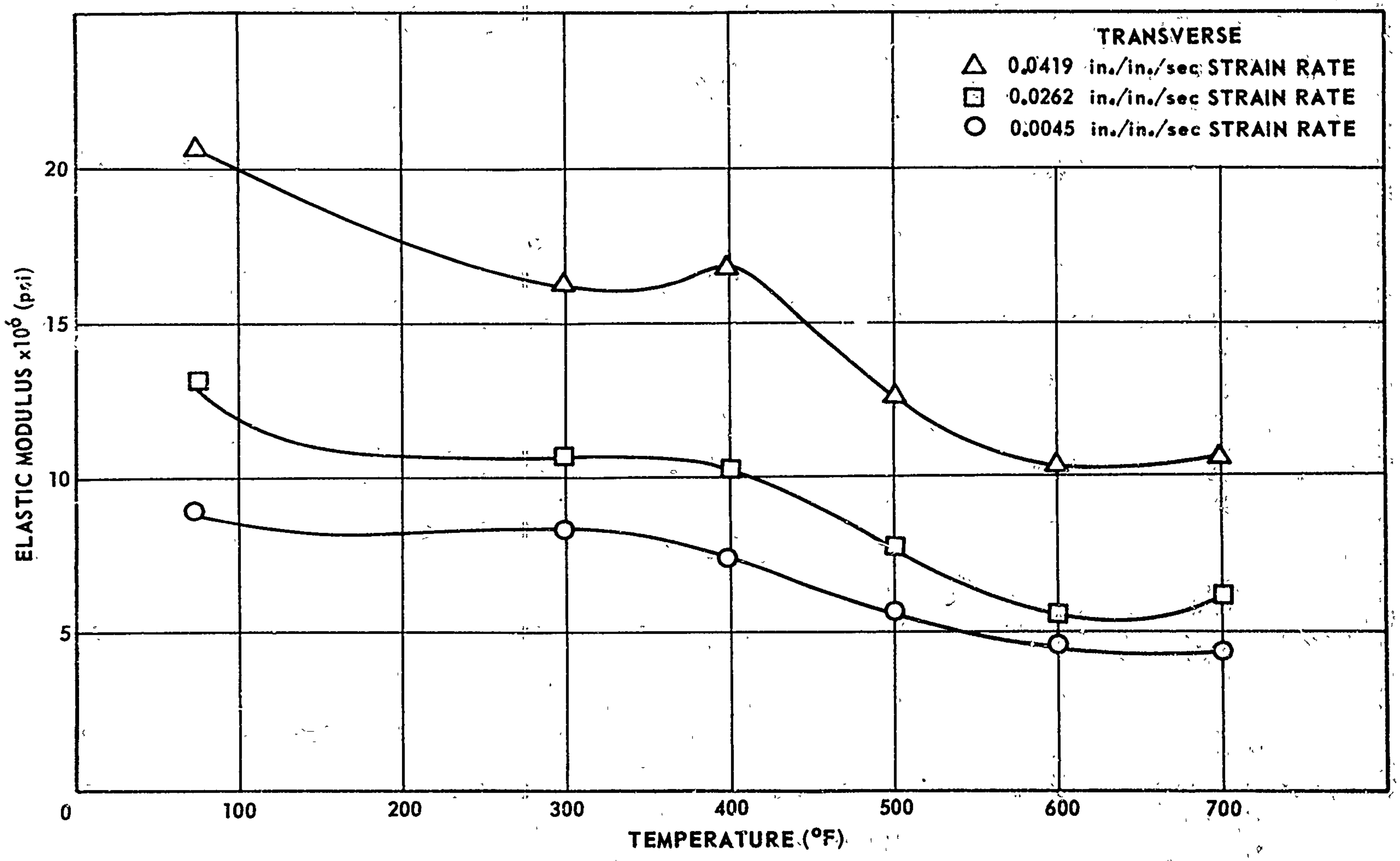


FIGURE 15. EFFECT OF TEMPERATURE ON ELASTIC MODULUS OF TRANSVERSE SPECIMENS AT DIFFERENT STRAIN RATES

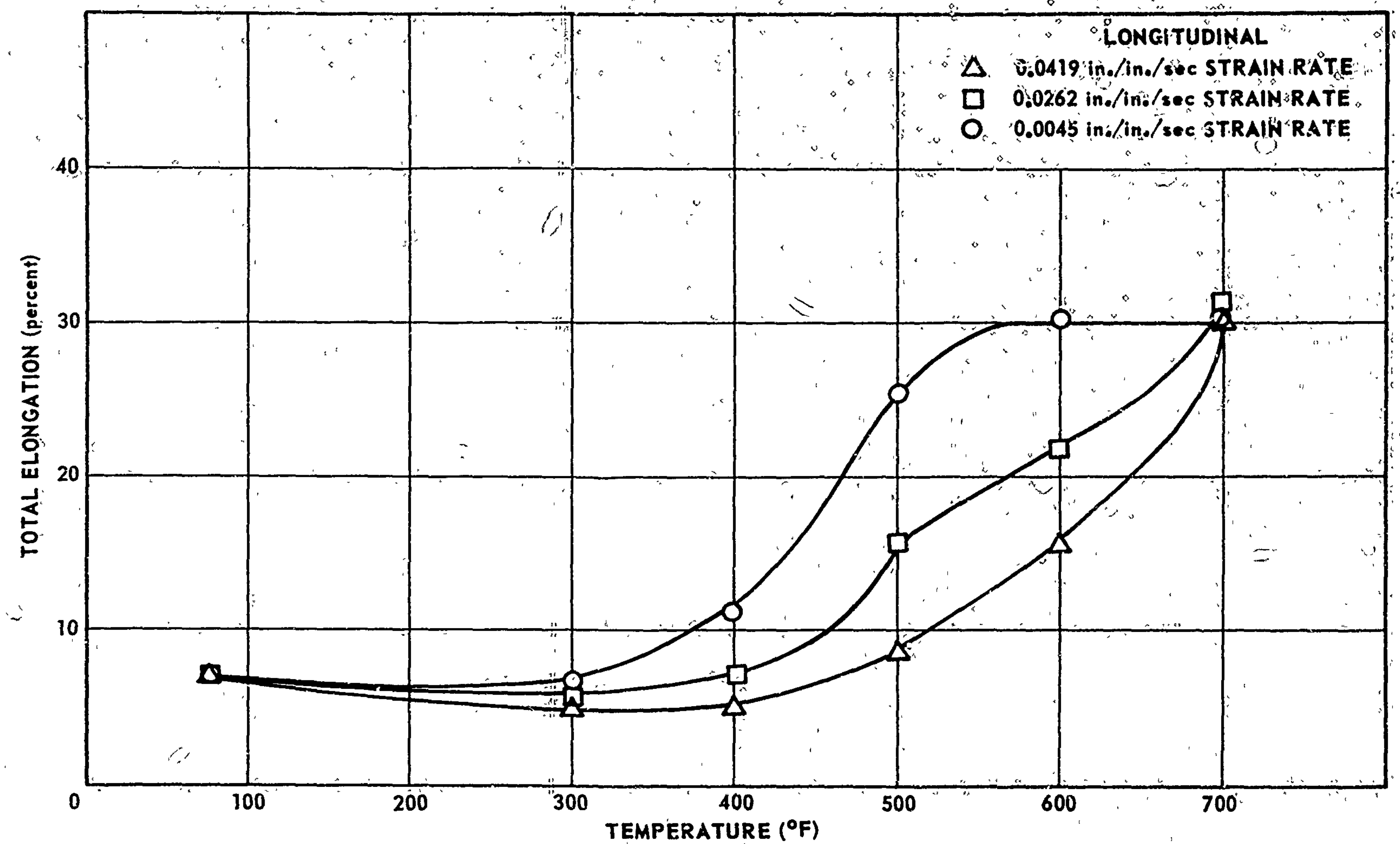


FIGURE 16. EFFECT OF TEMPERATURE ON TOTAL ELONGATION OF LONGITUDINAL SPECIMENS AT DIFFERENT STRAIN RATES

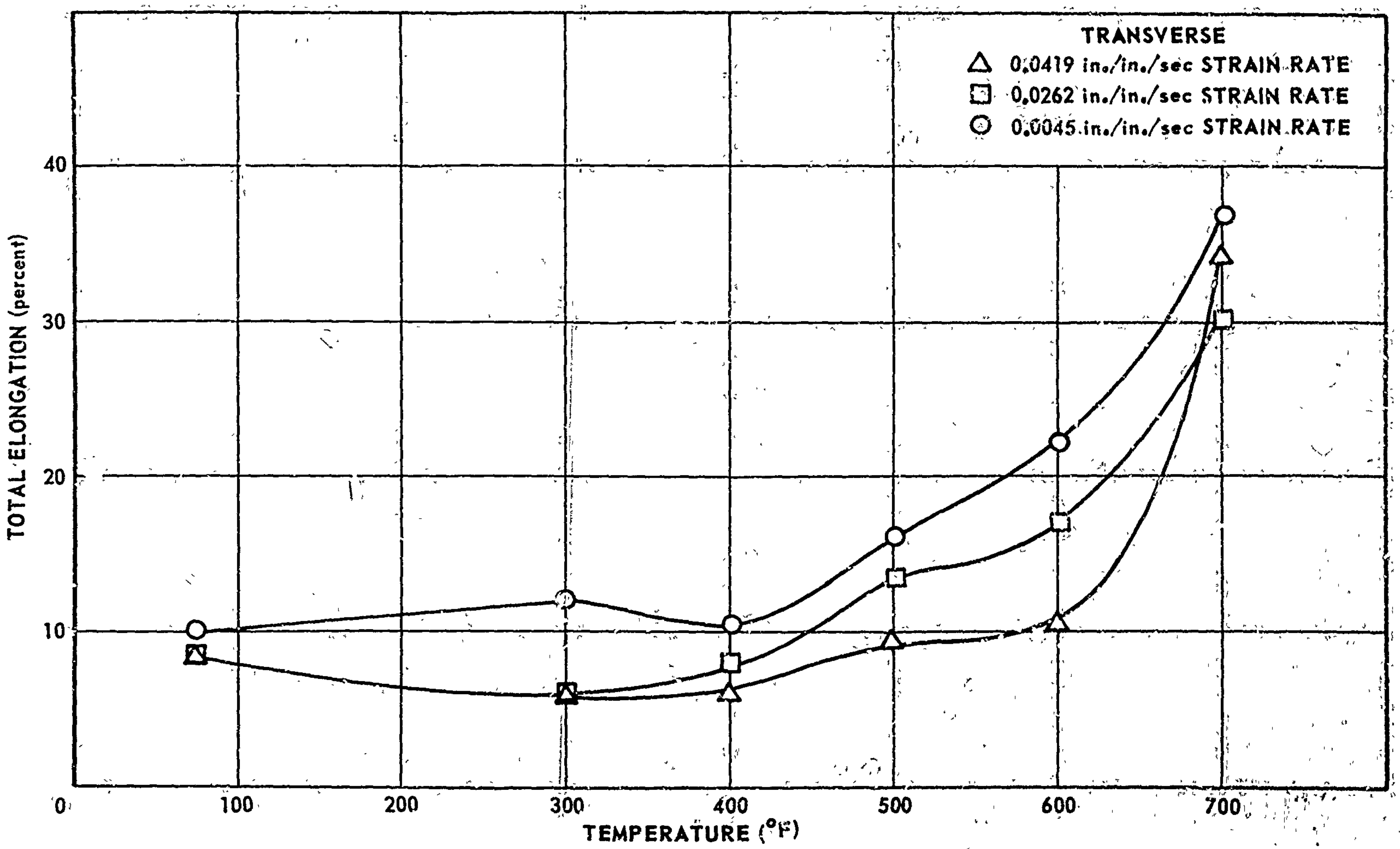


FIGURE 17. EFFECT OF TEMPERATURE ON TOTAL ELONGATION OF TRANSVERSE SPECIMENS AT DIFFERENT STRAIN RATES

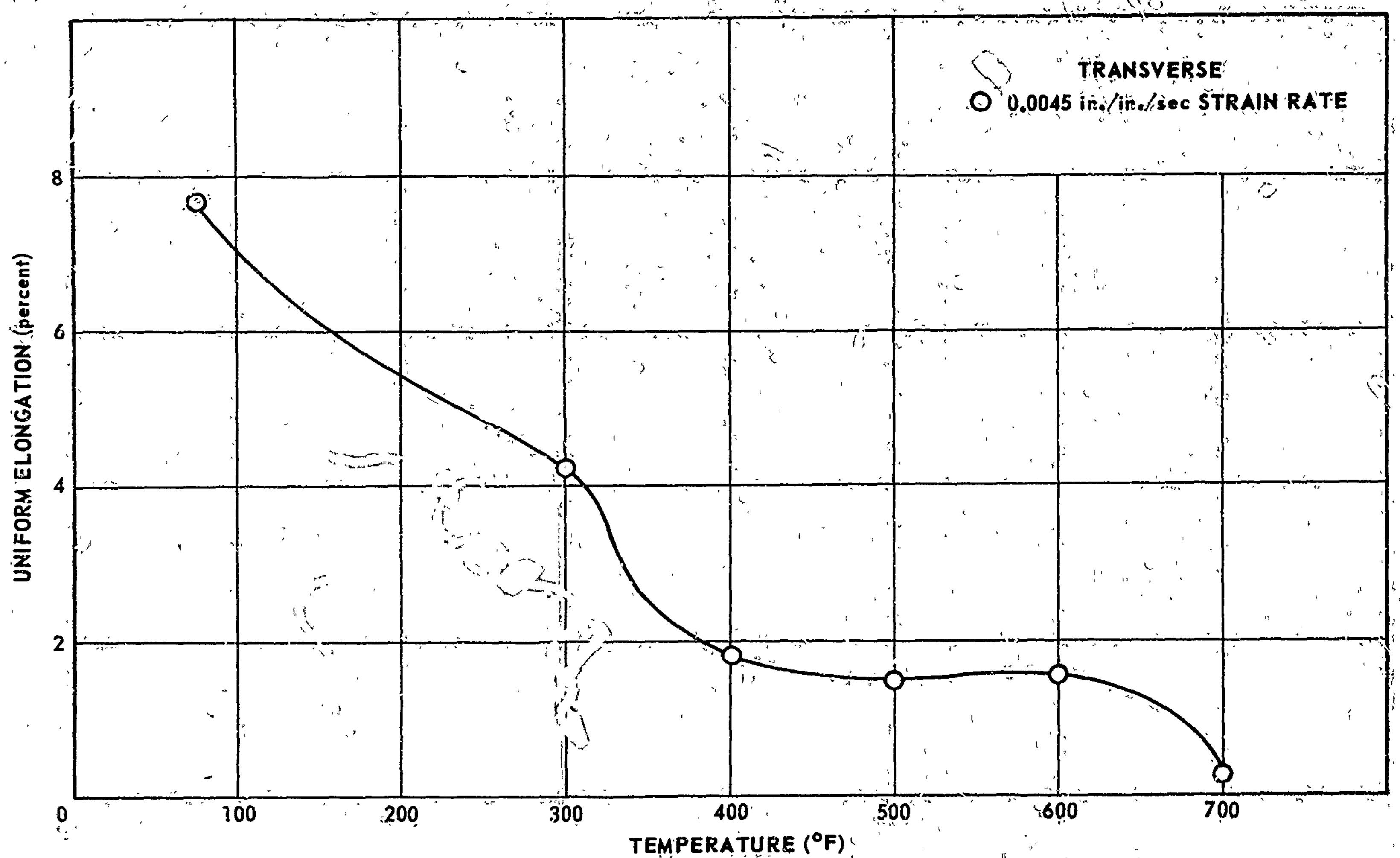


FIGURE 18. EFFECT OF TEMPERATURE ON UNIFORM ELONGATION OF TRANSVERSE SPECIMENS

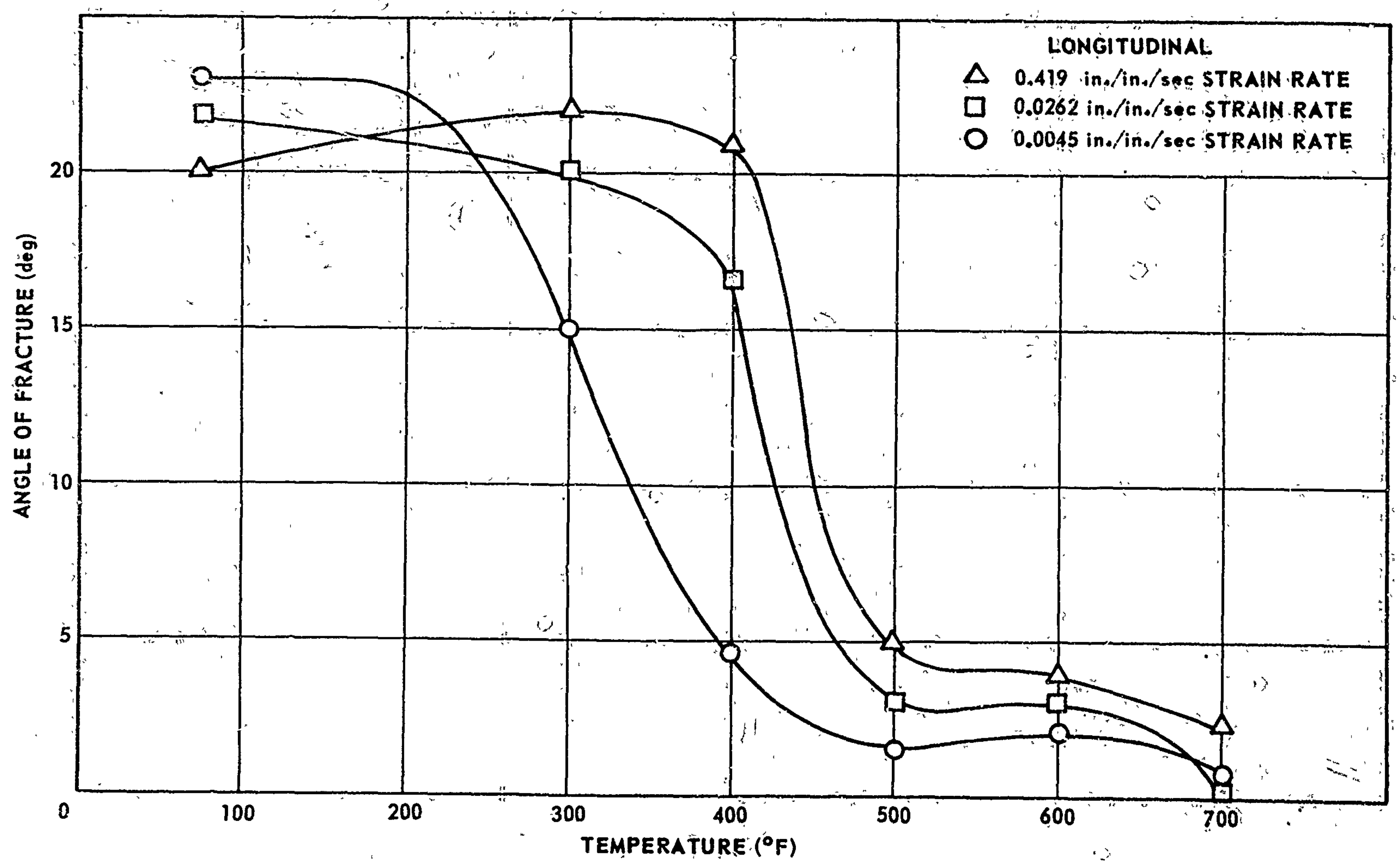


FIGURE 19. EFFECT OF TEMPERATURE ON ANGLE OF FRACTURE OF LONGITUDINAL SPECIMENS AT DIFFERENT STRAIN RATES

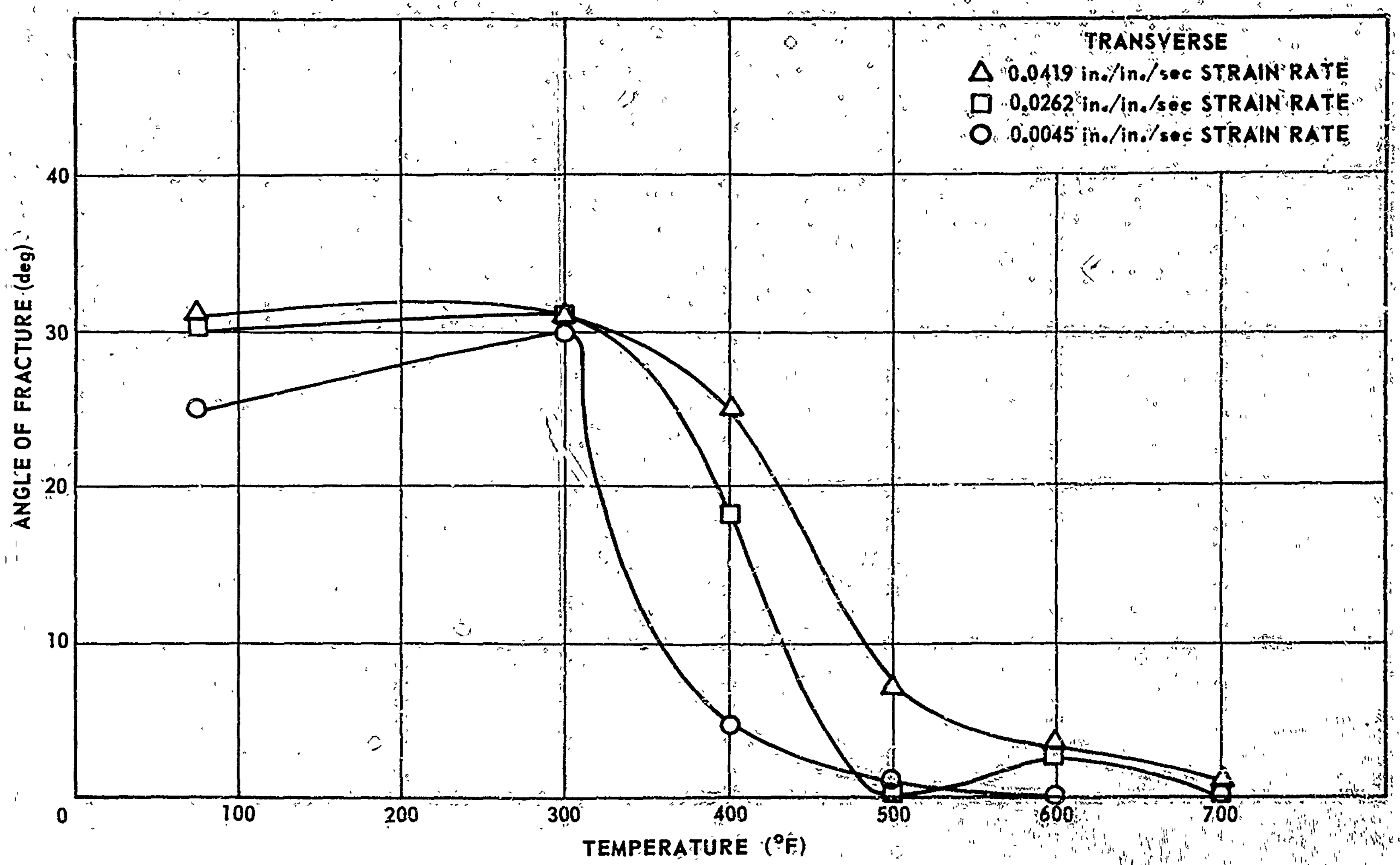


FIGURE 20. EFFECT OF TEMPERATURE ON ANGLE OF FRACTURE OF TRANSVERSE SPECIMENS AT DIFFERENT STRAIN RATES

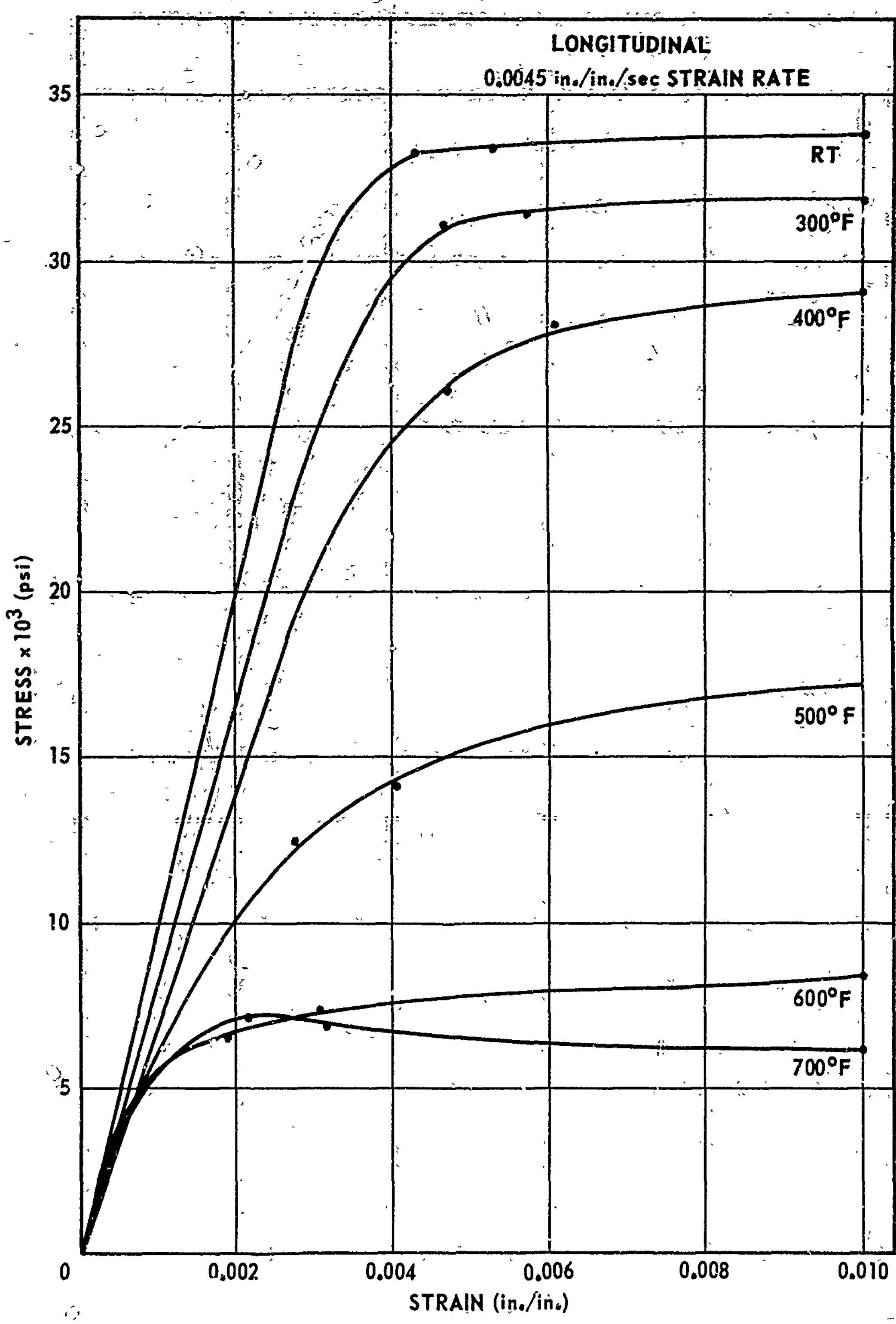


FIGURE 21. STRESS-STRAIN CURVES FOR LONGITUDINAL SPECIMENS AT DIFFERENT TEMPERATURES

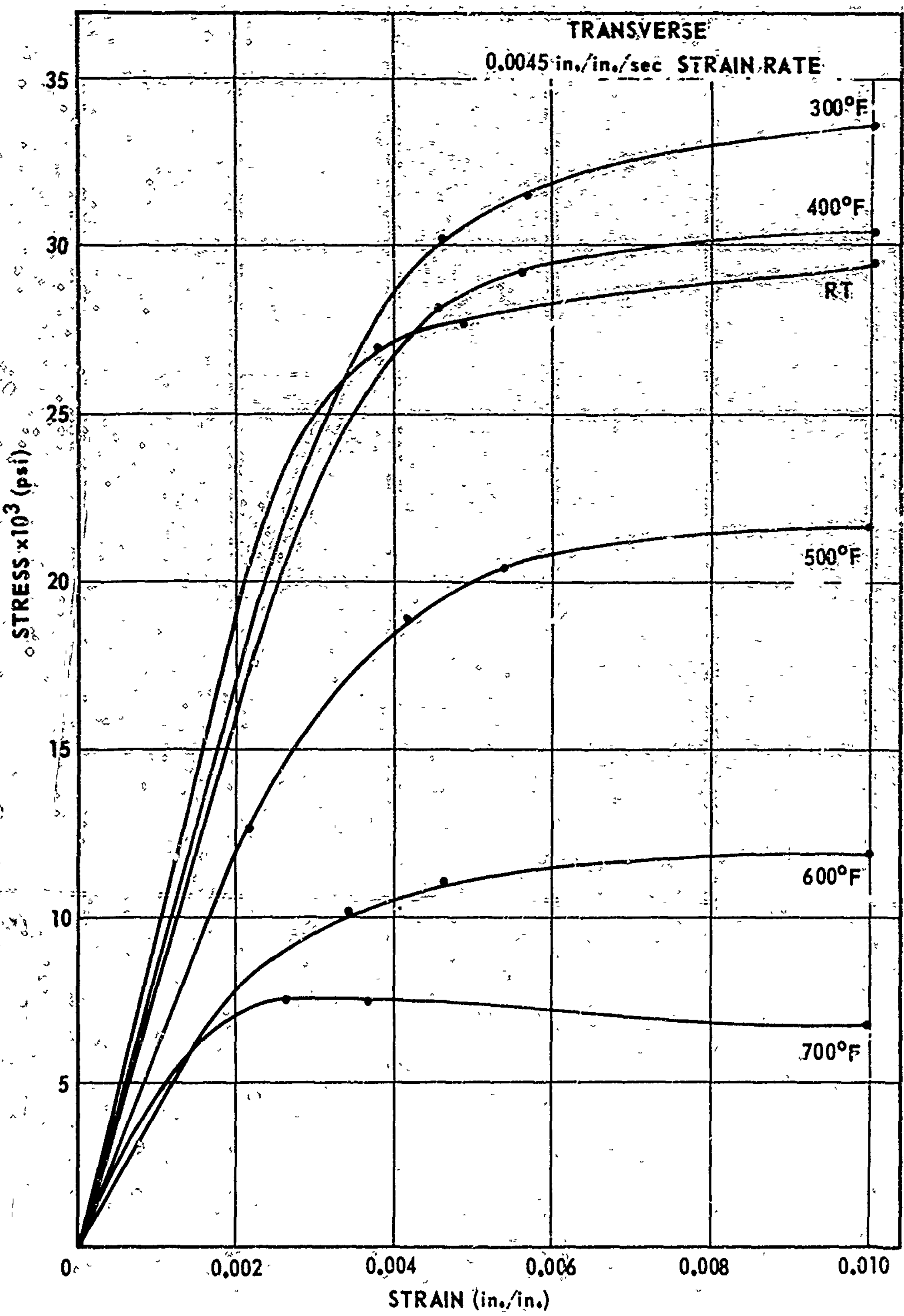


FIGURE 22. STRESS-STRAIN CURVES FOR TRANSVERSE SPECIMENS AT DIFFERENT TEMPERATURES

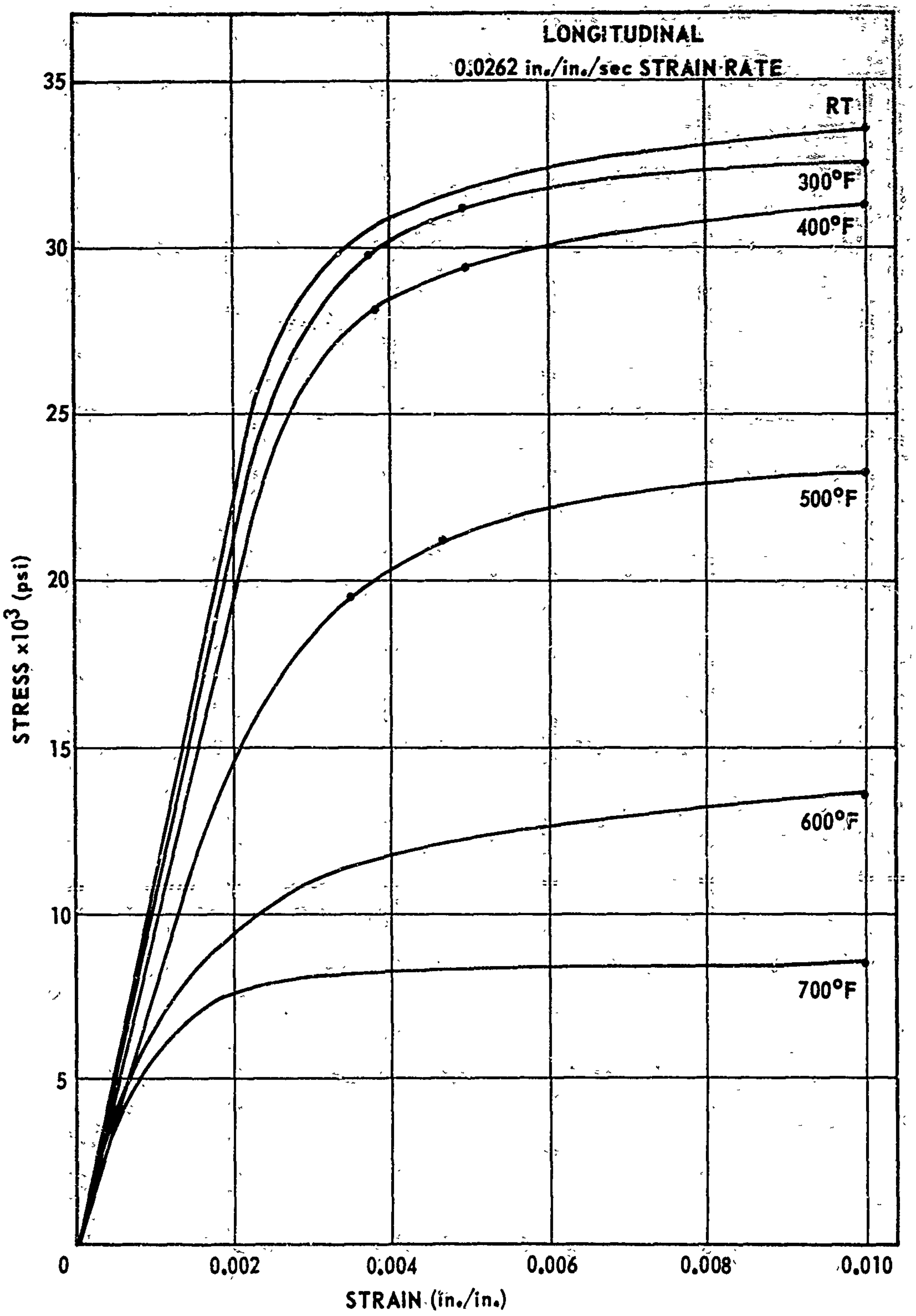


FIGURE 23. STRESS-STRAIN CURVES FOR LONGITUDINAL SPECIMENS AT DIFFERENT TEMPERATURES

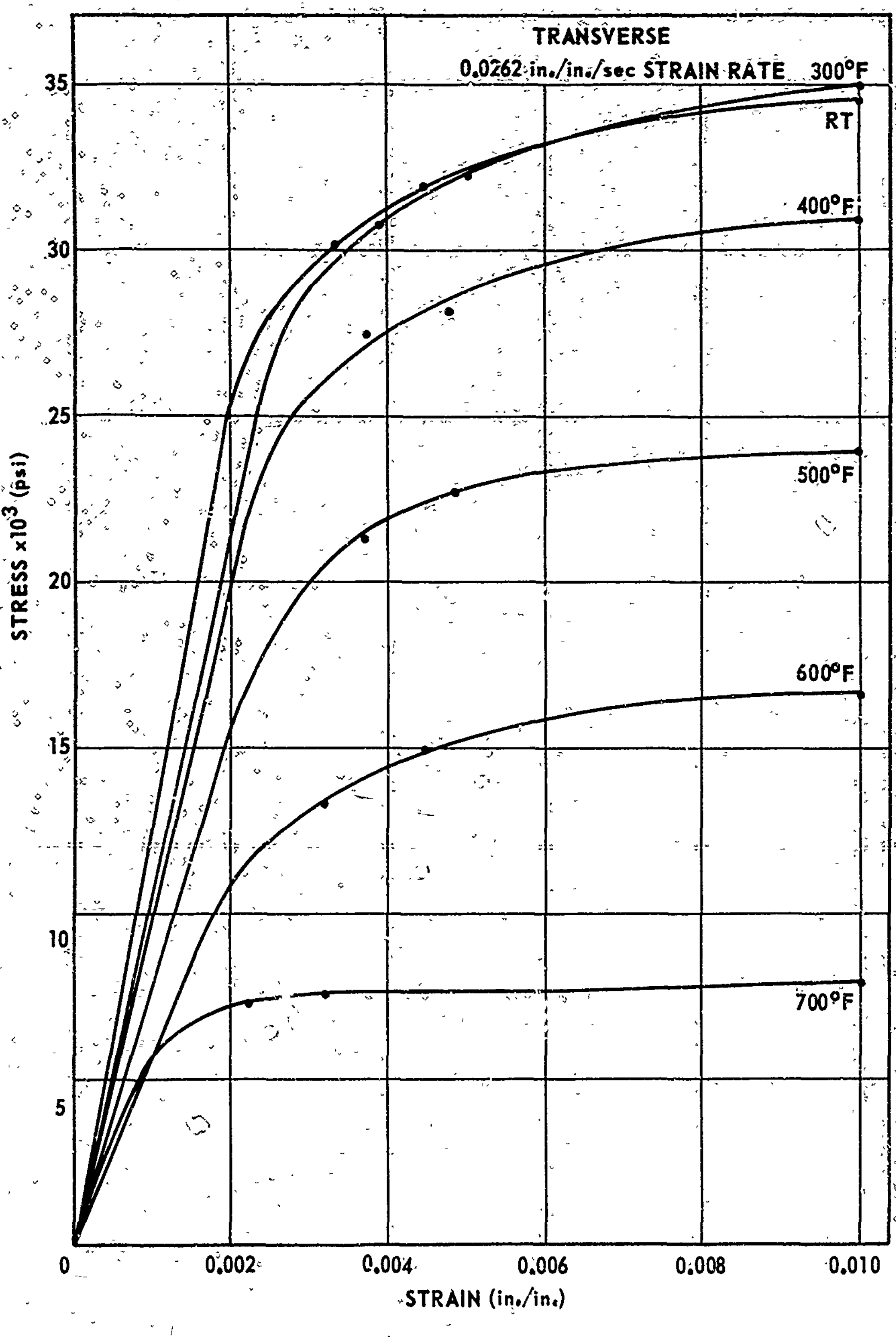


FIGURE 24. STRESS-STRAIN CURVES FOR TRANSVERSE SPECIMENS AT DIFFERENT TEMPERATURES

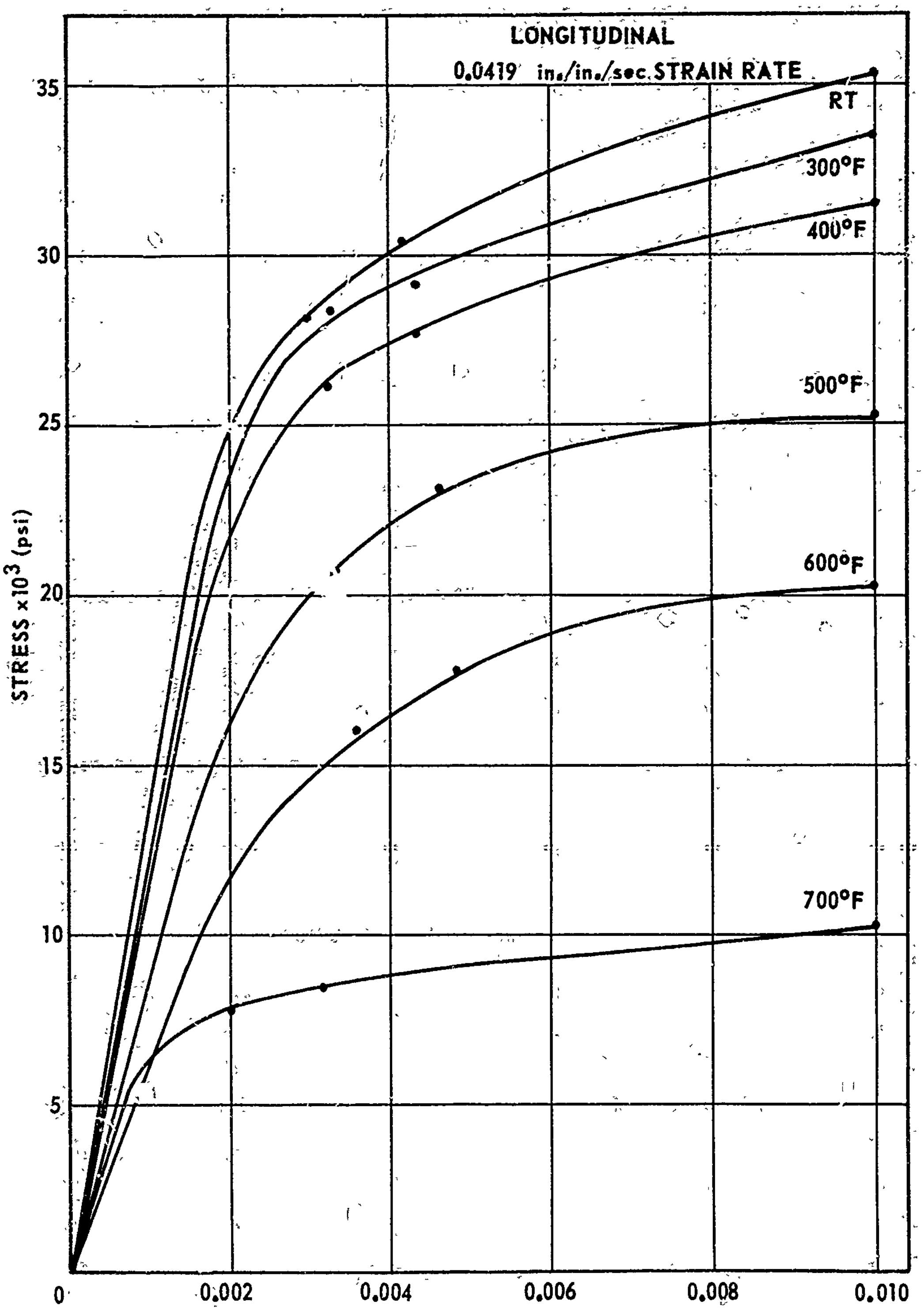


FIGURE 25. STRESS-STRAIN CURVES FOR LONGITUDINAL SPECIMENS AT DIFFERENT TEMPERATURES

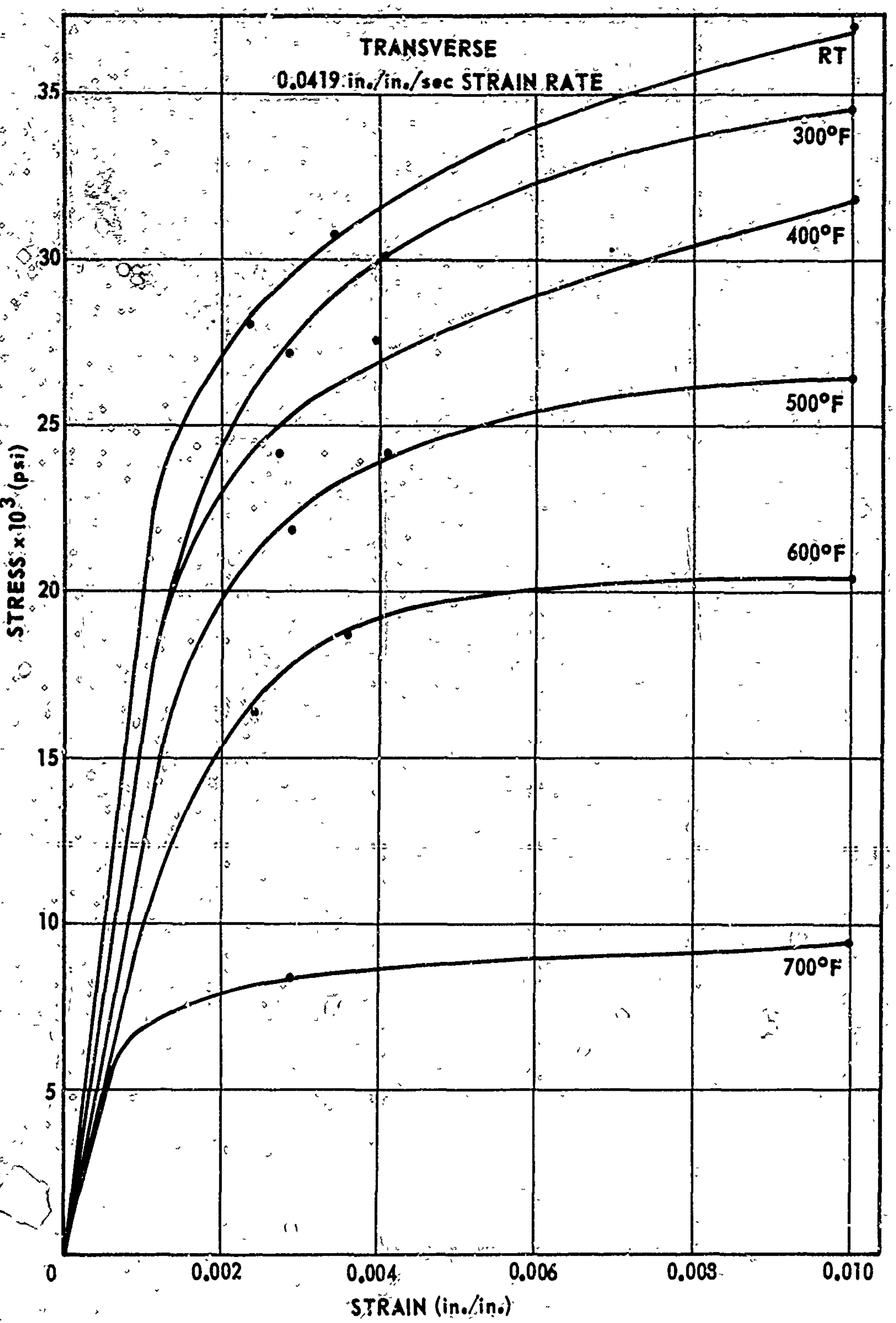


FIGURE 26. STRESS-STRAIN CURVES FOR TRANSVERSE SPECIMENS AT DIFFERENT TEMPERATURES

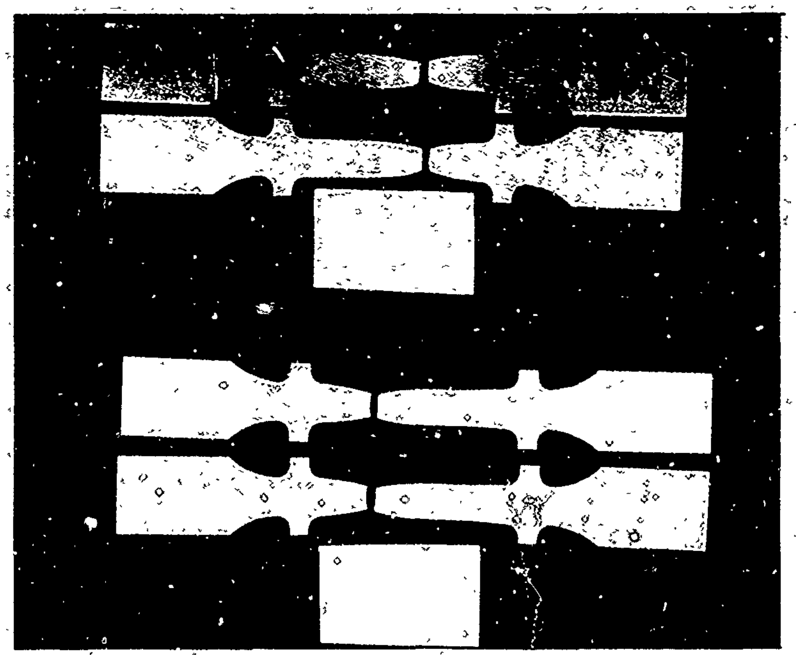


FIGURE 27. SAMPLES SHOWING ARCING AND MELTING AT FRACTURE SECTION AND THOSE THAT DO NOT SHOW ARCING AND MELTING

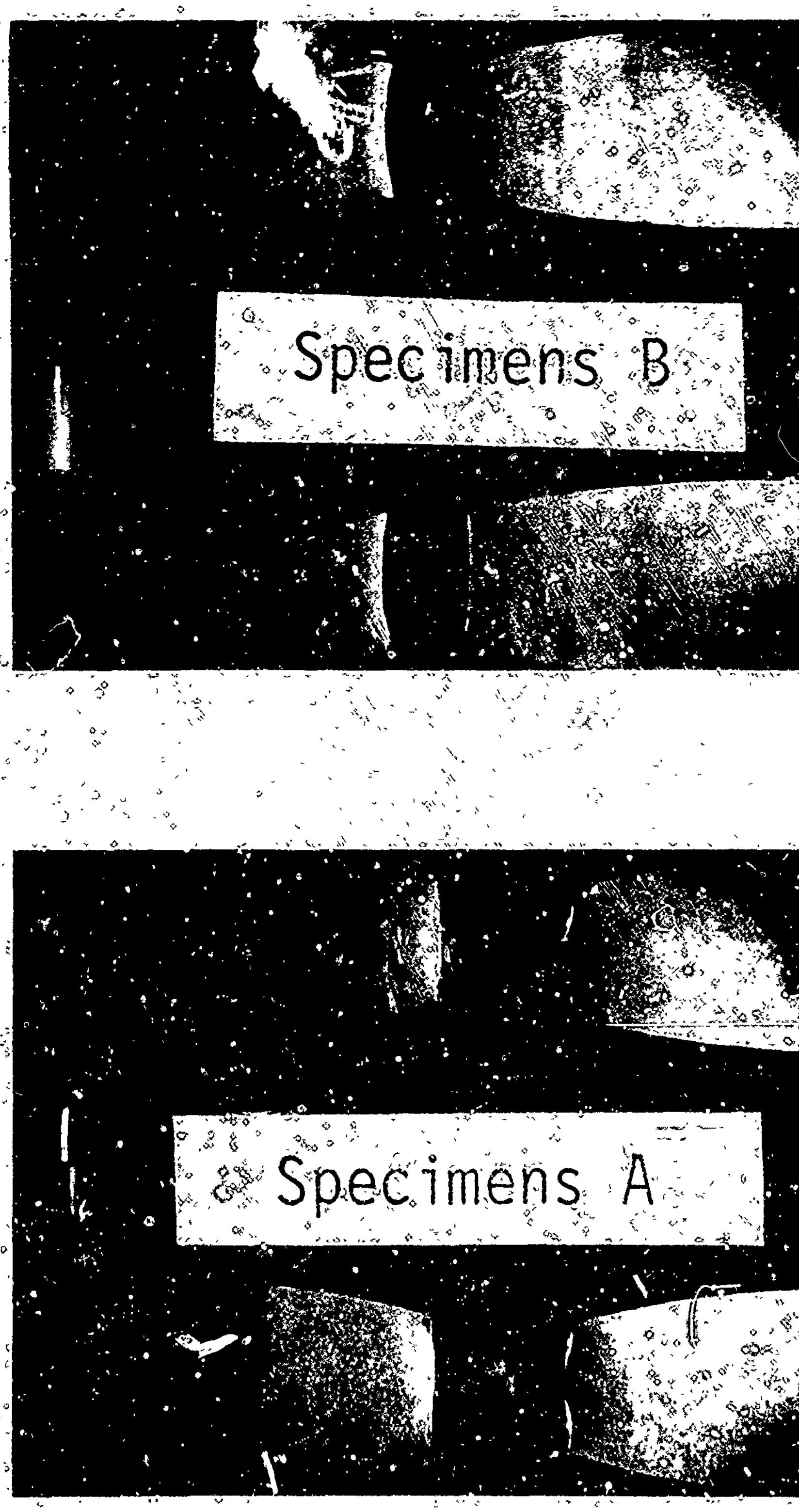


FIGURE 28. ENLARGEMENT OF FIGURE 10

UNCLASSIFIED
Security Classification

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(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

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3. REPORT TITLE

RAPID HEATING AND LOADING OF 5052-H34 ALUMINUM ALLOY SHEET

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

None

5. AUTHOR(S) (First name, middle initial, last name)

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
None	Same as No. 1

13. ABSTRACT

The purpose of this report is to make available to the design engineer tensile property data on 5052-H34 aluminum under conditions of rapid heating and loading.

The tensile property data reported are: ultimate tensile stress, ultimate yield stress (at 0.2 percent offset), elastic modulus, percent total elongation, and percent uniform elongation. The uniform elongation was determined only at 0.0045 in./in./sec on the transverse specimens.

These tensile properties were determined at strain rates of 0.0045, 0.0262, and 0.0419 in./in./sec and at temperatures from room temperature (78°F) to 700°F at 100-degree intervals, excluding 100° and 200°F. The time required to reach the test temperature was, in most cases, less than 10 seconds.

In addition to the tensile property data, the angle of fracture of the material was also determined. These data are presented as byproducts of the tensile property data and only to investigate the possibility of establishing a trend for the angle of fracture at different strain rates and temperatures.

Primary consideration is given to ultimate tensile and yield properties. Other tensile property data reported are secondary and should be used for design criteria only after consideration has been given to the methods used for obtaining and reducing these data.

The strength properties of the test material increased with an increase in strain rate from 400° to 700°F. However, from room temperature to 400°F, the strength properties showed almost no change with respect to strain rate.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Tensile property data						
5052-H34 aluminum						
Angle of fracture						

ABSTRACT (Concluded)

All tensile data indicated a decreasing trend with an increase in temperature except for total elongation, which established an increasing trend with an increase in temperature.